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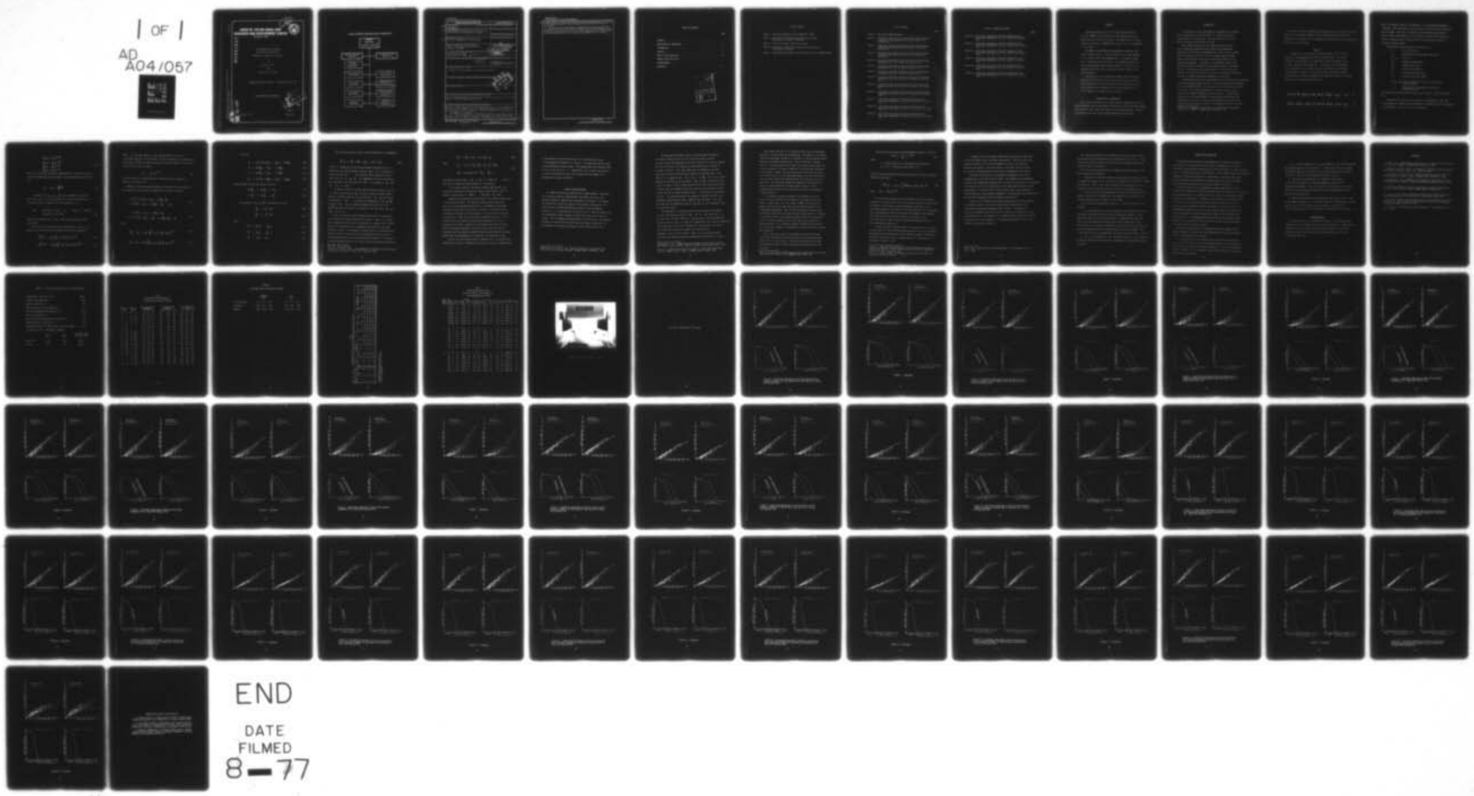

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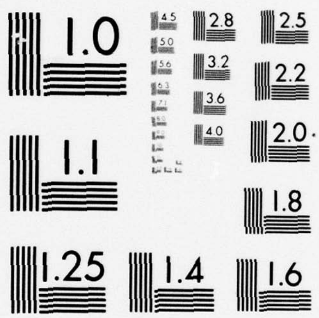

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INVESTIGATION OF EFFECTS OF ACTIVATED FINS ON VERTICAL MOTION OF A SWATH SHIP IN WAVES

by

Choung M. Lee

and

Kathryn K. McCreight

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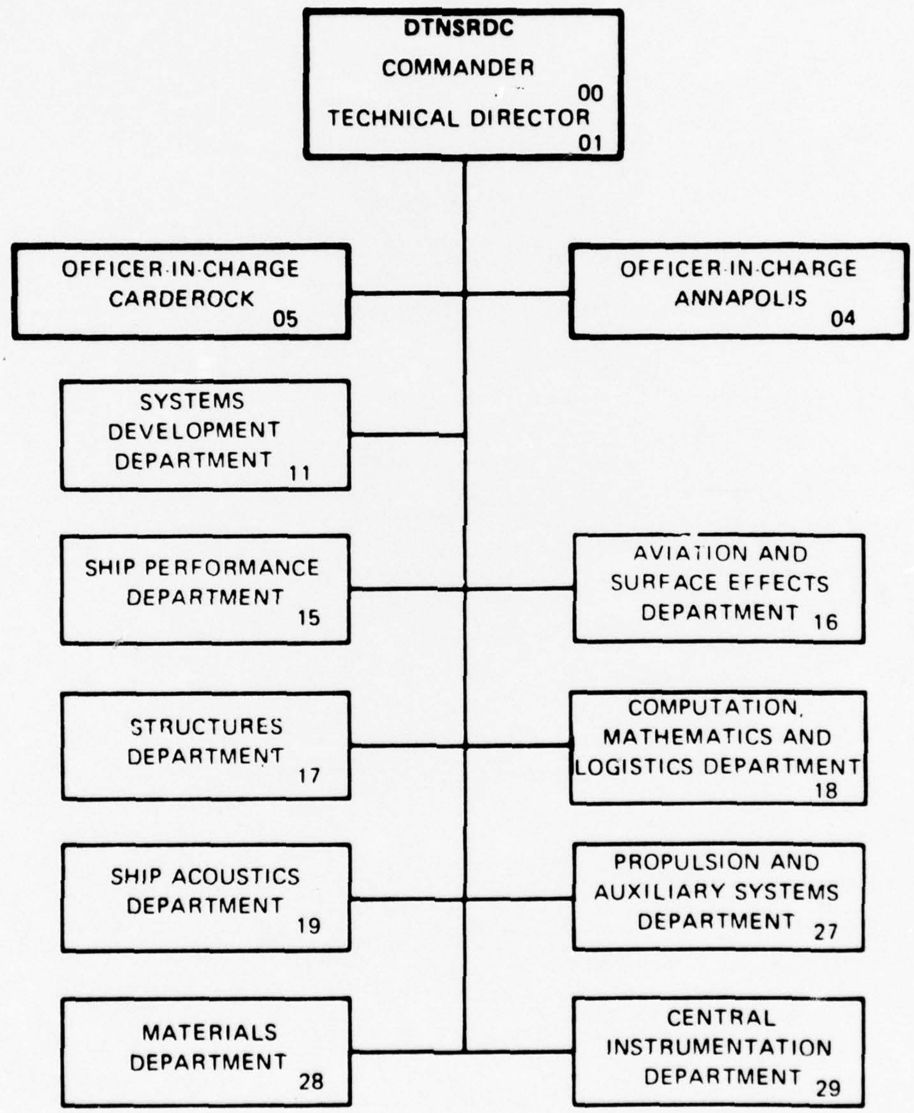

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Stationary stabilizing fins of a small waterplane area, twin-hull (SWATH) ship are known to be an effective device to damp the motion of the ship in waves. The feasibility of further reduction of motion of a SWATH ship by active fins is investigated in this report.

The SWATH ship examined has displacement of 2400 tons and overall length of 70 m. It has two pairs of fins, each attached to the inboard side of the submerged hull, in a canard arrangement. The analysis was carried out in the

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frequency domain by seeking optimum amplitudes and phase angles of fin motion in a frequency band within which the maximum vertical motion of the ship would occur.

The results of the investigation revealed that the vertical motion at the midship and the aft end of the cross deck can be further reduced by 10 to 20 percent by activating the fins of the total projected area of about 45 m^2 in the sea states up to 5 in the range of ship speed from 5 to 15 knots.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

ABSTRACT

Stationary stabilizing fins of a small waterplane area, twin-hull (SWATH) ship are known to be an effective device to damp the motion of the ship in waves. The feasibility of further reduction of motion of a SWATH ship by active fins is investigated in this report.

The SWATH ship examined has displacement of 2400 tons and overall length of 70 m. It has two pairs of fins, each attached to the inboard side of the submerged hull, in a canard arrangement. The analysis was carried out in the frequency domain by seeking optimum amplitudes and phase angles of fin motion in a frequency band within which the maximum vertical motion of the ship would occur.

The results of the investigation revealed that the vertical motion at the midship and the aft end of the cross deck can be further reduced by 10 to 20 percent by activating the fins of the total projected area of about 45 m^2 in the sea states up to 5 in the range of ship speed from 5 to 15 knots.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

In the design of a mine countermeasure ship (MCM) which is planned to tow a sonar array, one of the criteria is a certain limit on the vertical motion at the tow points. The lesser the motion at the tow points, the better the performance for a MCM.

Small waterplane area, twin-hull (SWATH) configurations were found through model experiments to have some desirable seakeeping characteristics which could be advantageous for a MCM. That is, a SWATH ship with stationary stabilizing fins at a moderate speed could have smaller vertical motion in waves than a conventional monohull ship of comparable displacement. Furthermore, it is reasonable to expect that the vertical motion of a SWATH ship can be reduced further by activating the fins. The objective of the present study is to find out how much reduction in the vertical motion at a tow point could be made by activating the fins, if a SWATH configuration were adopted for a MCM ship.

The SWATH configuration studied was geometrically similar (geosim) to SWATH 6A[1] with the displacement of 2400 long tons. This scaled-down version of SWATH 6A will be called SWATH 6A-2400. This ship has a pair of forward fins and a pair of aft fins. The principal characteristics are given in Table 1 and a bow view of the model of SWATH 6A is given in Figure 1. The analysis was carried out in the frequency domain by seeking the optimum amplitudes and phase angles of fin motion of the tow points assumed to be located at the aft end of the cross deck, the midship, or the forward end of the cross deck.

[1] Kallio, J.A. "Seaworthiness Characteristics of 2900-Ton Small Waterplane Area Twin Hull (SWATH)," DTNSRDC Report SPD-620-03, 1977.

The results for the idealized control model used in this investigation show that a 10 to 20 percent reduction in the vertical motion at a tow point located aft of midships can be achieved by activating fins in sea states up to 5 for a 5 to 15-knot range.

ANALYSIS

A SWATH ship is cruising with a constant speed in the direction opposite to the propagation of a chain of regular waves. Due to the symmetry of the body about its centerplane, the ship undergoes motion in surge, heave and pitch modes only. On the basis of the slenderness of the submerged hull, we assume that the surge mode can be decoupled from the other two modes. If we assume a linear relationship between the wave excitation and ship response, the equations of motion for coupled heave and pitch modes can be described by

$$(M + A_{33})\ddot{\xi}_3 + B_{33}\dot{\xi}_3 + C_{33}\xi_3 + A_{35}\ddot{\xi}_5 + B_{35}\dot{\xi}_5 + C_{35}\xi_5 = F_3(t) \qquad (1)$$

$$A_{53}\ddot{\xi}_3 + B_{53}\dot{\xi}_3 + C_{53}\xi_3 + (I_5 + A_{55})\ddot{\xi}_5 + B_{55}\dot{\xi}_5 + C_{55}\xi_5 = F_5(t) \qquad (2)$$

Here, the reference frame for the equations is a right-handed rectangular coordinate system translating in the direction of the ship's mean course with the ship speed. The origin is located on the calm-water plane directly above or below the mean position of the center of gravity of the ship; the x-axis is directed toward the mean course of the ship and the z-axis is directed vertically upward.

The notations used in Equations (1) and (2) are:

M	= mass of the ship
I_5	= mass moment of inertia about the y-axis
For i, j	= 3 and 5:
A_{ij}	= added mass coefficient
B_{ij}	= damping coefficient
C_{ij}	= restoring coefficient
F_3	= wave-exciting heave force
F_5	= wave-exciting pitch moment
ξ_3 ($\dot{\xi}_3$, $\ddot{\xi}_3$)	= heave displacement (velocity, acceleration), positive upward
ξ_5	= pitch angular displacement, positive for bow-down position

The coefficients defined above include the contributions from the stationary fins.

We assume that F_3 and F_5 have a harmonic-time dependence. Then, due to the property of linearity of the equations, the response of the ship ξ_3 and ξ_5 will be harmonic in time. That is, we can express

$$
\begin{aligned}
F_3(t) &= f_3\, e^{-i\omega t} \\
F_5(t) &= f_5\, e^{-i\omega t} \\
\xi_3(t) &= \bar{\xi}_3\, e^{-i\omega t} \\
\xi_5(t) &= \bar{\xi}_5\, e^{-i\omega t}
\end{aligned}
\tag{3}
$$

where ω is the wave encountering frequency which is defined in terms of the wave frequency ω_o, the ship speed U, and gravitational acceleration g by

$$\omega = \omega_o + \frac{\omega_o^2}{g} U \tag{4}$$

In Equation (3), f_3, f_5, ξ_3 and ξ_5 are supposed to be complex amplitudes, and it is tacitly assumed that only the real part of the right-hand side of the equations will be realized, e.g.,

$$
\begin{aligned}
F_3(t) &= \text{Real part of } [(f_{3R} + i\, f_{3I})\,(\cos\omega t - i\sin\omega t)] \\
&= f_{3R}\cos\omega t + f_{3I}\sin\omega t
\end{aligned}
\tag{5}
$$

where the subscripts R and I refer to the real and imaginary parts, respectively.

When the fins are activated with the frequency ω, the fins will generate vertical force and pitch moment which can be expressed by

$$F_3^{(f)}(t) = \rho U^2 \sum_{j=1}^{2} c_j\, s_j\, C_{L\delta_j}\, \bar{\delta}_j\, e^{-i\omega t} \tag{6}$$

$$F_5^{(f)}(t) = -\rho U^2 \sum_{j=1}^{2} c_j\, s_j\, C_{L\delta_j}\, \ell_j\, \bar{\delta}_j\, e^{-i\omega t} \tag{7}$$

Here, ρ is the water density, c_j the average chord of the jth fin, s_j the span, $C_{L\delta_j}$ the lift-curve slope, ℓ_j the x-coordinate of the one-quarter-chord point, and $\bar{\delta}_j$ the complex amplitude of angle of attack of the j th fin which can be further defined as

$$\bar{\delta}_j = \delta_{jo} e^{-i\gamma_j} \tag{8}$$

for real values of δ_{jo} (amplitude) and γ_j (phase angle with respect to the wave crest below LCG).

Adding the force and moment produced by the active fins and substituting Equations (3) through (8) into Equations (1) and (2), we obtain

$$\begin{aligned} &[-\omega^2 (M + A_{33}) + C_{33} - i\omega B_{33}] \bar{\xi}_3 \\ &+ (-\omega^2 A_{35} + C_{35} - i\omega B_{35}) \bar{\xi}_5 = \bar{F}_3 \end{aligned} \tag{9}$$

$$\begin{aligned} &(-\omega^2 A_{53} + C_{53} - i\omega B_{53}) \bar{\xi}_3 \\ &+ [-\omega^2 (I_5 + A_{55}) + C_{55} - i\omega B_{55}] \bar{\xi}_5 = \bar{F}_5 \end{aligned} \tag{10}$$

where

$$\bar{F}_3 = f_3 + \rho u^2 \sum_{j=1}^{2} c_j \, s_j \, C_{L\delta_j} \, \delta_{jo} \, e^{-i\gamma_j} \tag{11}$$

$$\bar{F}_5 = f_5 - \rho u^2 \sum_{j=1}^{2} c_j \, s_j \, \ell_j \, C_{L\delta_j} \, \delta_{jo} \, e^{-i\gamma_j} \tag{12}$$

If we let

$$a = -\omega^2 (M + A_{33}) + C_{33} - i\omega B_{33} \tag{13}$$

$$b = -\omega^2 A_{35} + C_{35} - i\omega B_{35} \tag{14}$$

$$c = -\omega^2 A_{53} + C_{53} - i\omega B_{53} \tag{15}$$

$$d = -\omega^2 (I_5 + A_{55}) + C_{55} - i\omega B_{55} , \tag{16}$$

then Equations (9) and (10) can be written as

$$a\,\bar{\xi}_3 + b\,\bar{\xi}_5 = \bar{F}_3 \tag{17}$$

$$c\,\bar{\xi}_3 + d\,\bar{\xi}_5 = \bar{F}_5 \tag{18}$$

From Equations (17) and (18) we can easily find that

$$\bar{\xi}_3 = F_3' / D \tag{19}$$

$$\bar{\xi}_5 = F_5' / D \tag{20}$$

where

$$F_3' = \bar{F}_3\, d - \bar{F}_5\, b \tag{21}$$

$$F_5' = \bar{F}_5\, a - \bar{F}_3\, c \tag{22}$$

$$D = a d - b c \tag{23}$$

The vertical motion at a point with the coordinate x is obtained by

$$\bar{\xi}_v(x) = \bar{\xi}_3 - x\bar{\xi}_5 = (F_3' - x F_5')/D \tag{24}$$

Since D is independent of the force and moment generated by the fin deflection, the minimum absolute value of $\bar{\xi}_v(x)$ will be obtained by minimizing $|F_3' - x F_5'|$. The left-hand side of Equations (9) and (10) as well as f_3 and f_5 are independent of the fin deflections and, therefore, the minimization of $|\bar{\xi}_v|$ only depends on δ_{jo} and γ_j for j = 1 and 2.

To obtain a realistic solution for the optimum values of δ_{jo} and γ_j which would minimize $|\bar{\xi}_v|$ we have to impose acceptable upperbound for the amplitudes of the fin deflections δ_{jo} and the rate of the deflections $\dot{\delta}_{jo}$. If we denote the upperbound of δ_{jo} and $\dot{\delta}_{jo}$ by δ_{mj} and $\dot{\delta}_{mj}$, then the maximum allowable amplitude for the fin deflection should be chosen as the smaller of the two values δ_{mj} and $\dot{\delta}_{mj}$ for each ω .

Here, by taking a maximum allowable amplitude of fin deflection, we are imposing a rather inefficient fin control. That is, in reality when a saturation point of the fin deflection is reached, the fin can be kept at this deflection until a command to move the fin to the other direction is given. An incomplete sinusoidal motion with constant (flat) values at certain intervals of time during each half cycle of motion can be approximated by the so-called describing function.[2] If we are to use the describing function in our case, we have a new maximum deflection amplitude δ_{jo}' given by

[2]Chesnut, H. and R.W. Mayer, "Servomechanism and Regulating System Design," published by John Wiley, & Sons, Inc., New York, 1955.

$$\delta_{jo}' = \delta_{jo} \left(2\alpha_j + \sin 2\alpha_j \right) / \pi \tag{25}$$

where

$$\alpha_j = \sin^{-1} \left(\delta_{Lj} / \delta_{jo} \right) \quad \text{for } \delta_{jo} \geq \delta_{Lj}$$

$$\delta_{Lj} = \text{minimum of } \left(\delta_{mj} , \dot{\delta}_{mj} \right) \tag{26}$$

From Equation (25) we have $\delta_{Lj} \leq \delta_{jo}' \leq 4\,\delta_{Lj}/\pi$. Thus, we see that in a sense the present analysis is conservative.

In the present analysis the optimum values of δ_{jo}'s and γ_j's are sought by systematically varying the values of δ_{jo}'s and γ_j's until an apparent minimum value of $|\bar{\xi}_v(x)|$ is obtained. This crude

approach was considered to be practical in the present analysis due to the following reason. The SWATH ship examined here showed that when the fins are stationary and the ship is proceeding in head seas, the peak vertical motion of any point on the hull is dominated more by the heave motion than by the pitch motion. This fact implies that the minimization of $|\bar{\xi}_v|$ can be achieved by deflecting both fins in such a manner that the resultant vertical force produced by the fins is maximum and its sense is opposite to the wave-exciting vertical force. Thus, the aforesaid systematic variation of δ_{jo}'s and γ_j's can be perturbed about the maximum allowable deflection amplitudes and the phase angles which are 180 degrees out of phase with the argument of f_3 .

Once we find the optimum values of δ_{jo}'s and γ_j's by the aforesaid method for the range of frequencies of practical interest in SWATH motion,

we can compute the vertical motion at x with these optimum values. In the foregoing minimization of $|\bar{\xi}_v(x)|$, the wave amplitude was taken as one hundredth of the wave length. The response amplitude operator (RAO) of the vertical motion at x, $|\bar{\xi}_v(x)/A|^2$, can be readily obtained and is used to determine the statistical averages and the probability of exceedance for chosen sea spectra.

RESULTS AND DISCUSSIONS

The SWATH configuration examined here is SWATH 6A-2400. The search for the optimum values of δ_{jc}'s and γ_j's was made by the use of the computer program for SWATH motion developed at the Center.[3] The program was modified to include the purpose of the present investigation. The vertical motion of SWATH 6A-2400 was studied at three longitudinal locations, i.e., the forward end of the strut (0.11 x main hull-length (L)), the longitudinal center of gravity (0.48L) and the aft end of the strut (0.83L). The ship speeds considered were 5, 10 and 15 knots. The maximum allowable fin deflections and their rates were taken, respectively, as $\pm$ 20 degrees and 7 degrees per second for both forward and aft fins.

[3] McCreight, K.K. and C.M. Lee, "Manual for Mono-Hull or Twin-Hull Ship Motion Prediction Computer Program," DTNSRDC Report SPD-868-02, 1976.

To determine the optimum values of the amplitudes and phases of fin motion, various sets of initial values were chosen, and the vertical motions were computed at the three locations for the three speeds. The results of the initial search for the optimum values of δ_{jo} and γ_j are shown in Table 2. The values shown under the speeds are the peak amplitudes of the vertical motion divided by the wave amplitude. From Table 2, it is apparent that $\delta_{1o} = \delta_{2o} = 20$ deg and $\gamma_1 = \gamma_2 = 204.5$ degrees can be taken as optimum values. Here, we mean, by optimum values, simply the values of δ_{jo}'s and γ_j's which minimize the vertical motion most. To ensure that the foregoing values are close to the true optimum values, a check was made by another approach called minimization of constrained function. The algorithm based on the method of feasible directions was developed at Ames Research Center, NASA[4] and was used here. This check confirmed that the foregoing values of δ_{jo} and γ_j were reasonably close to the optimum values.

The reduction in the peak vertical motion achieved by the movable fins with the aforesaid values of δ_{jo} and γ_j was significant. It was felt that a further reduction in the peak motion could be obtained by increasing the fin sizes. To check this expectation, the projected areas of both the forward and aft fins were increased first by 50 percent and then by 100 percent while keeping the aspect ratios and locations unchanged. The lift curve slopes of these fins for fixed and movable conditions are computed according to Reference 5 and are given in Table 3.

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[4] Vanderplaats, G.N., "CONMIN-A Fortran Program for Constrained Function Minimization, User's Manual," NASA TM X-62,282, Ames Research Center, 1973

[5] Lee, C.M., "Theoretical Prediction of Motion of Small-Waterplane-Area, Twin-Hull (SWATH) Ships in Waves," DTNSRDC Report 76-0046, 1976.

Table 4 shows the effect of fin activation and fin size on the maximum amplitude of vertical motion per wave amplitude. The numbers in the brackets indicate the percentage increase (+) or decrease (-) from the maximum vertical motion of the original stationary fins. The fin area factor indicate the ratio of the plane area of the larger fins to that of the original fins. As can be expected, an increase in speed and fin size decreases the maximum vertical motion. However, for the stationary fins having twice the plane area of the original fins, the maximum amplitudes of vertical motion at the LCG are slightly greater than those obtained by the stationary fins of 1.5 area factor. This seemingly contradictory phenomenon is considered to be caused by the deterioration of the heave stability when fin size is increased beyond a certain limit as was found in an earlier investigation on SWATH stability.[6]

It is premature to assess the effects of the movable fins on the vertical motion by examing only the reduction in the peak values of the motion in regular waves. As is well known, a SWATH ship has relatively greater natural periods of heave and pitch than those of monohull ships of comparable displacement. Thus, for the sea conditions which have much smaller modal periods than the natural periods of heave and pitch, a reduction in the vertical motion in the resonant frequency range may not necessarily result in a smaller reduction in the overall statistical average of the motion amplitude. It is, therefore, important to determine the reduction of the statistical average of the amplitude of the vertical motion for overall wave frequencies.

Table 5 shows the results of the averages of the one-third highest (significant) amplitudes of the vertical motion at the three longitudinal locations for 5, 10 and 15 knots. The results are obtained by using the Pierson-Moskowitz spectra for the significant wave amplitude from 2 feet to 16 feet.

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[6] Lee, C.M. and M. Martin, "Determination of Size of Stabilizing Fins for Small Waterplane Area, Twin-Hull Ships," DTNSRDC Report 4495, 1974

The formula used to obtain the Pierson-Moskowitz spectra is given by

$$S(\omega_o) = \frac{C_1}{\omega_o^5} e^{-C_2/\omega_o^4} \tag{27}$$

where

$C_1 = 0.0081\ g$ where g is the gravitational acceleration

$C_2 = 3.12\ /$ (significant wave height in m)^2

The significant amplitude of the vertical motion for any given sea spectrum $S(\omega_o)$ can be obtained by

$$(\xi_v)_{1/3} = 2.0 \left[\int_0^\infty RAO(\omega_o)\, S(\omega_o)\, d\omega_o \right]^{\frac{1}{2}} \tag{28}$$

where RAO = $|\bar{\xi}_v(x) / A|^2$

The results are presented for three different sizes of fins and, for comparison, the results for the fixed fin of the original size are also given. The numbers in the brackets indicate percentage of the change in the significant amplitude with respect to the fixed condition. As is well known, the Pierson-Moskowitz formula for wave spectra represents fully developed sea conditions which are not always the case in real oceans. Thus, the results shown in Table 5 should be regarded as meaningful only for fully-developed sea conditions.

In order to examine the effectiveness of the active fins in a variety of ocean conditions, the significant amplitudes of the vertical displacement and acceleration were computed by using a stratified sample of wave spectra obtained at the Station India in the North Atlantic.[7] The results are presented in Figures 2 to 19.*

[7] Miles, M., "Wave Spectra Estimated from a Stratified Sample of 323 North Atlantic Wave Records," National Research Council, Division of Mechanical Engineering, Report LTR-SH-118, 1971.

*Due to the limited funding, the computer-plotted figure scales were not converted to the metric system.

In Figures 2 to 10, the upper figures show the significant amplitude of vertical motion versus significant wave heights. Each cross point represents the motion of the ship corresponding to one of the stratified sample of wave spectra. The solid curves in the upper figures represent the vertical motion obtained by using the Pierson-Moskowitz wave spectra.

The lower figures show the percentage of exceedance of the motion corresponding to the figure directly above. The probability of exceedance indicates the probable percentage of the time that a given value will be exceeded in an overall sum of the time durations of the individual 323 Station India wave spectra. The lower curve of the two curves shown in each exceedance figure represents the percentage exceedance of the significant motion amplitudes and the other represents the most probable extreme value.[8]

Figures 11 to 19 show the significant amplitudes of vertical acceleration (upper figures) in the unit of gravitational acceleration g and corresponding percentage exceedance (lower figures). The various fin sizes are indicated by the ratio of the fin area of the original fin to the larger geosim fins. For example, Fin 1.5 means the fins which have 1.5 times the plane area of the original fin. The geometric characteristics of the original fin are given in Table 1.

[8] Ochi, M.K., "On Prediction of Extreme Values," J. Ship Research, Vol. 17, No. 1, 1973.

The figures are exhibited in the order of 5, 10 and 15 knots at each longitudinal location beginning with the forward end of the strut. In each figure, the results are shown for four different fins beginning with the original fixed fin on the left.

For the significant amplitude of the absolute motion (Figures 2 - 10), the following can be observed:

1. Reduction of the absolute motion can be achieved by activating fins. The greater the speed, the fin area and the distance from the bow, the greater the reduction. That is, the largest reduction of the absolute motion is achieved at the aft end of the strut at 15 knots by the movable fin 2.0.

2. As can be inferred from Equations (6) and (7), the reduction of the absolute motion can be achieved more significantly by an increase in the forward speed than by an increase in the fin area.

For the vertical accelerations (Figures 11 - 19) the following can be observed:

1. At the forward end of strut, the greater the speed and the fin area, the greater the reduction of the vertical acceleration; however, as the location at which the vertical acceleration is computed moves toward the stern, the trend becomes less obvious than at the forward end of strut. The reduction in the vertical acceleration at the aft end of strut does not seem to be obtained by merely increasing the fin area or the speed. This is particularly so for the significant wave height less than 3.05 m (10 ft.).

2. For a given speed and fin size, the best reduction in the vertical acceleration among the three locations is obtained at the longitudinal center of gravity.

SUMMARY AND CONCLUSIONS

The objective of the present investigation was to examine the extent of the reduction in the absolute vertical motion of a SWATH ship wich can be achieved by activating the stabilizing fins which are placed in a canard arrangement. The theoretical analysis was performed in the frequency domain using coupled equations of heave and pitch motion in head waves. The active stabilizing fins were treated as the producer of external heave force and pitch moment which counteract the wave-exciting force and moment on the ship.

Within the constraints of 20 degrees for maximum amplitude of fin deflections and 7 degrees per second for maximum rate of fin deflections, the optimum amplitude and phase for fin deflections in the vicinity of the heave resonant frequency were determined. The absolute vertical motions at the forward end of the strut, at the longitudinal center of gravity, and at the aft end of the strut were computed for three ship speeds, 5, 10, and 15 knots. To investigate the effect of fin size on the vertical motion, the projected fin area was increased by 50 and 100 percent for each fin while retaining the same aspect ratio. The computations were carried out by using the Pierson-Moskowitz wave spectra and a stratified sample of wave spectra obtained at the Station India in the North Atlantic.

The results from the present investigation should be regarded as the maximum reduction in the vertical motion obtainable with maximum deflection of fins. The findings are as follows:

1. By activating fins, the absolute vertical motion and acceleration at points on the ship hull can be reduced significantly; the greater the fin size and the ship speed, the greater the reduction in vertical displacement; however, increase in fin size should be made within the bound of maintaining sufficient heave stability.

2. For a given speed and fin size, the reduction in the vertical displacement becomes greater as the tow point is moved toward the stern; however, the maximum reduction in the vertical acceleration seems to be achieved at tow point in the vicinity of longitudinal center of gravity.

3. The vertical accelerations of a SWATH ship even without fin activation are smaller in magnitude compared to monohulls of comparable displacement. Thus, the necessity of activating the fins seems more justified for reducing the absolute vertical displacements than for the vertical accelerations.

4. Based on the overall results obtained by the current study, it can be concluded that about a 10 to 20 percent reduction in the absolute vertical motion at points aft of midships can be obtained by activating the fins in sea states up to 5 in the range of ship speed from 5 to 15 knots.

ACKNOWLEDGMENTS

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4. Vanderplaats, G.N., "CONMIN-A Fortran Program for Constrained Function Minimization, User's Manual," NASA TM X-62,282, Ames Research Center, 1973.

5. Lee, C.M., "Theoretical Prediction of Motion of Small-Waterplane-Area Twin-Hull (SWATH) Ships in Waves," DTNSRDC Report 76-0046, 1976.

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7. Miles, M., "Wave Spectra Estimated from a Stratified Sample of 323 North Atlantic Wave Records," National Research Council, Division of Mechanical Engineering, Report LTR-SH-118, 1971.

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TABLE 1 - Principal Characteristics of SWATH 6A-2400

Displacement, long tons in S.W.	2400
Length at the Waterline, m	50.5
Length of Main Hull, m	70.4
Beam of Each Hull at the Waterline, m	2.1
Hull Spacing between the Centerlines, m	22.0
Draft at the Midship, m	7.8
Bridging Structure Clearance from Waterline, m	5.9
Maximum Diameter of Main Hull, m	4.4
Longitudinal Center of Gravity Aft of Main Hull Nose, m	34.1

Fin Characteristics : Rectangular Planform

	Chord m	Span m	Distance From Main Hull Nose m
Forward Fin	2.49	2.99	16.49
Aft Fin	4.31	5.15	59.84

TABLE 2

MAXIMUM VERTICAL MOTION AMPLITUDES PER

UNIT WAVE AMPLITUDE WITH VARIOUS FIN MOTIONS

Fwd Fin (Deg.)		Aft Fin (Deg.)		Max. Absolute Motion at Forward			Max. Absolute Motion at LCG			Max. Absolute Motion Aft		
δ_{10}	σ_1	δ_{20}	σ_2	.114	.227	.341	F_n=.144	.227	.341	.114	.227	.341
0	0	0	0	2.51	2.16	1.91	2.16	1.85	1.64	1.94	1.63	1.50
0	0	20	204.5	2.38	1.91	1.71	2.05	1.60	1.34	1.78	1.32	.99
0	0	20	114.5	2.38	1.78	1.25	2.11	1.71	1.39	1.95	1.70	1.59
0	0	20	24.5	2.65	2.47	2.41	2.26	2.10	2.03	2.08	1.98	2.05
20	204.5	0	0	2.44	2.00	1.72	2.10	1.70	1.43	1.89	1.52	1.35
20	114.5	0	0	2.54	2.29	2.16	2.16	1.89	1.76	1.92	1.60	1.49
20	24.5	0	0	2.57	2.32	2.13	2.22	1.99	1.85	1.98	1.73	1.64
20	204.5	20	204.5	2.31	1.73	1.42	1.99	1.45	1.12	1.74	1.21	1.00
20	114.5	20	204.5	2.40	2.01	1.85	2.05	1.63	1.40	1.77	1.29	.99
20	24.5	20	204.5	2.44	2.10	2.01	2.11	1.75	1.55	1.83	1.42	1.13
20	204.5	15	204.5	2.32	1.77	1.43	2.00	1.48	1.16	1.75	1.24	1.00
20	204.5	15	114.5	2.33	1.68	1.21	2.06	1.58	1.24	1.90	1.58	1.42
20	204.5	15	24.5	2.57	2.30	2.19	2.19	1.93	1.79	2.03	1.87	1.89
20	204.5	10	204.5	2.36	1.84	1.49	2.03	1.55	1.24	1.80	1.34	1.04
20	204.5	10	114.5	2.37	1.78	1.36	2.07	1.62	1.29	1.90	1.55	1.34
20	204.5	10	24.5	2.53	2.19	2.02	2.16	1.85	1.67	1.98	1.75	1.70
0	0	10	204.5	2.43	2.00	1.75	2.09	1.70	1.45	1.84	1.44	1.18
0	0	10	114.5	2.43	1.93	1.51	2.13	1.76	1.48	1.94	1.66	1.53
0	0	10	24.5	2.59	2.29	2.16	2.22	2.00	1.87	2.03	1.85	1.83
15	204.5	5	204.5	2.41	1.94	1.63	2.07	1.64	1.36	1.85	1.44	1.21

TABLE 3

LIFT-CURVE SLOPE OF VARIOUS FIN AREAS

	FORWARD FIN			AFT FIN		
Fin Area Factor	1.0	1.5	2.0	1.0	1.5	2.0
Stationary	4.38	4.01	3.72	3.43	2.97	2.80
Movable	2.99	2.80	2.68	2.43	2.30	2.23

TABLE 4

REDUCTION OF MAXIMUM VERTICAL MOTION* BY MOVABLE FINS OF DIFFERENT FIN AREAS

Fin Area Factor	Forward Fins (deg.)		Aft. Fins (deg.)		Location Forward Deck End			LCG			Aft Deck End		
	δ_{10}	γ_1	δ_{20}	γ_2	5(knots)	10	15	5	10	15	5	10	15
1.0	0	0	0	0	2.51	2.16	1.91	2.16	1.85	1.64	1.94	1.62	1.50
1.0	20	204.5	20	204.5	2.31(-8)	1.73(-20)	1.42(-26)	1.99(-8)	1.45(-22)	1.12(-26)	1.74(-10)	1.21(-25)	1.00(-33)
1.5	0	0	0	0	2.49(-1)	2.09(-3)	1.79(-6)	1.98(-8)	1.63(-12)	1.45(-11)	1.72(-11)	1.47(-9)	1.35(-10)
1.5	20	204.5	20	204.5	2.23(-11)	1.58(-27)	1.31(-31)	1.85(-14)	1.25(-32)	1.01(-38)	1.52(-22)	1.00(-38)	1.00(-33)
2.0	0	0	0	0	2.49(-1)	2.03(-6)	1.71(-10)	2.06(-5)	1.68(-9)	1.51(-8)	1.57(-19)	1.34(-17)	1.28(-15)
2.0	20	204.5	20	204.5	2.19(-13)	1.47(-32)	1.25(-35)	1.69(-22)	1.12(-40)	1.00(-39)	1.33(-31)	1.00(-38)	1.00(-33)

*The numbers designate the maximum amplitude of vertical motion (among different wave lengths) divided by wave amplitude.

TABLE 5

SIGNIFICANT AMPLITUDE OF VERTICAL

MOTION (m) OF SWATH 6A - 2400 WITH MOVABLE FINS

USING PIERSON-MOSKOWITZ WAVE SPECTRA

Ship Speed (Knots)	Sig. Wave Ht. m (Ft)	Forward Fixed 1.0	Forward Active 1.0(%)	Forward Active 1.5	Forward Active 2.0	LCG Fixed 1.0	LCG Active 1.0	LCG Active 1.5	LCG Active 2.0	AFT Fixed 1.0	AFT Active 1.0	AFT Active 1.5	AFT Active 2.0
5	0.61(2)	.01	.01(0)	.01	.01	.01	.01(0)	.01	.01	.01	.01(0)	.01	.01
	1.22(4)	.05	.17(0)	.05	.05	.04	.03(-25)	.03	.03	.06	.06(0)	.05	.05
	1.83(6)	.18	.17(-6)	.15	.13	.18	.16(-11)	.13	.11	.22	.19(-14)	.16	.14
	2.44(8)	.61	0.45(-8)	.50	.45	.59	0.53(-11)	.45	.39	.62	.54(-13)	.44	.37
	3.05(10)	1.30	1.19(-8)	1.09	1.00	1.20	1.09(-9)	.95	.84	1.17	1.03(-12)	.86	.73
	3.66(12)	2.07	1.90(-8)	1.78	1.68	1.87	1.70(-9)	1.52	1.37	1.74	1.56(-10)	1.32	1.13
	4.27(14)	2.85	2.62(-8)	2.50	2.40	2.51	2.30(-8)	2.09	1.92	2.28	2.05(-10)	1.76	1.54
	4.88(16)	2.60	3.32(-8)	3.20	3.11	3.12	2.87(-8)	2.64	2.45	2.76	2.51(-9)	2.18	1.91
10	0.61	.01	.01(0)	.01	.01	.00	.01	.01	.01	.01	.01(0)	.02	.02
	1.22	.03	.04(33)	.03	.03	.02	.02(0)	.03	.03	.05	.05(0)	.02	.06
	1.83	.08	.08(0)	.08	.08	.09	.05(-44)	.05	.06	.16	.09(-44)	.08	.09
	2.44	.28	.22(-21)	.19	.17	.30	.20(-33)	.15	.13	.39	.22(-44)	.17	.14
	3.05	.72	.56(-22)	.46	.39	.71	.50(-30)	.38	.31	.78	.48(-38)	.36	.28
	3.66	1.32	1.04(-21)	.86	.74	1.24	.91(-27)	.72	.59	1.27	.83(-34)	.62	.48
	4.27	2.01	1.59(-21)	1.36	1.18	1.83	1.37(-25)	1.11	.92	1.78	1.22(-31)	.93	.73
	4.88	2.73	2.18(-20)	1.89	1.66	2.43	1.86(-23)	1.54	1.30	2.29	1.51(-30)	1.25	1.00
15	0.61	.01	.01(0)	0	0	0	.01	.01	.01	.01	.02(+100)	.02	.02
	1.22	.03	.03(0)	.03	.03	.02	.02(0)	.03	.04	.04	.05(25)	.06	.07
	1.83	.07	.08(+14)	.08	.09	.06	.05(-17)	.07	.09	.13	.07(-46)	.09	.11
	2.44	.17	.13(-24)	.14	.16	.19	.09(-53)	.10	.12	.30	.10(-67)	.11	.13
	3.05	.44	.29(-33)	.25	.24	.46	.23(-50)	.17	.18	.59	.20(-66)	.14	.15
	3.66	.87	.57(-34)	.45	.39	.87	.46(-47)	.32	.27	.98	.38(-61)	.23	.18
	4.27	1.42	.95(-33)	.75	.62	1.35	.77(-43)	.54	.41	1.44	.62(-57)	.36	.25
	4.88	2.03	1.39(-31)	1.11	.91	1.89	1.12(-41)	.80	.61	1.93	.88(-54)	.54	.35

Figure 1 - Bow View of SWATH 6A Model

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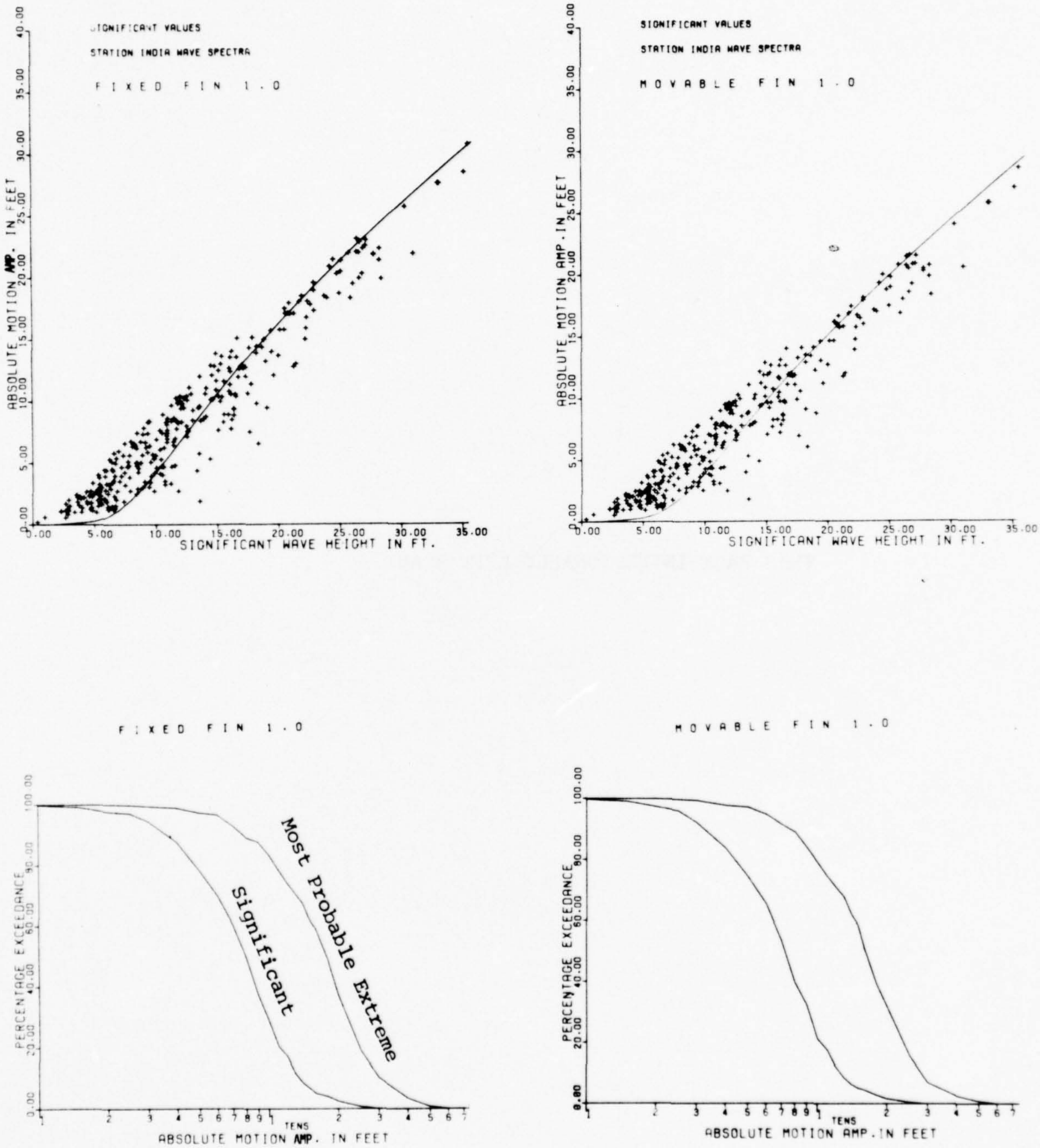


Figure 2 - Significant Amplitude of Vertical Motion and Percentage Exceedance at the Forward End of the Strut for 5 Knots with Various Fins

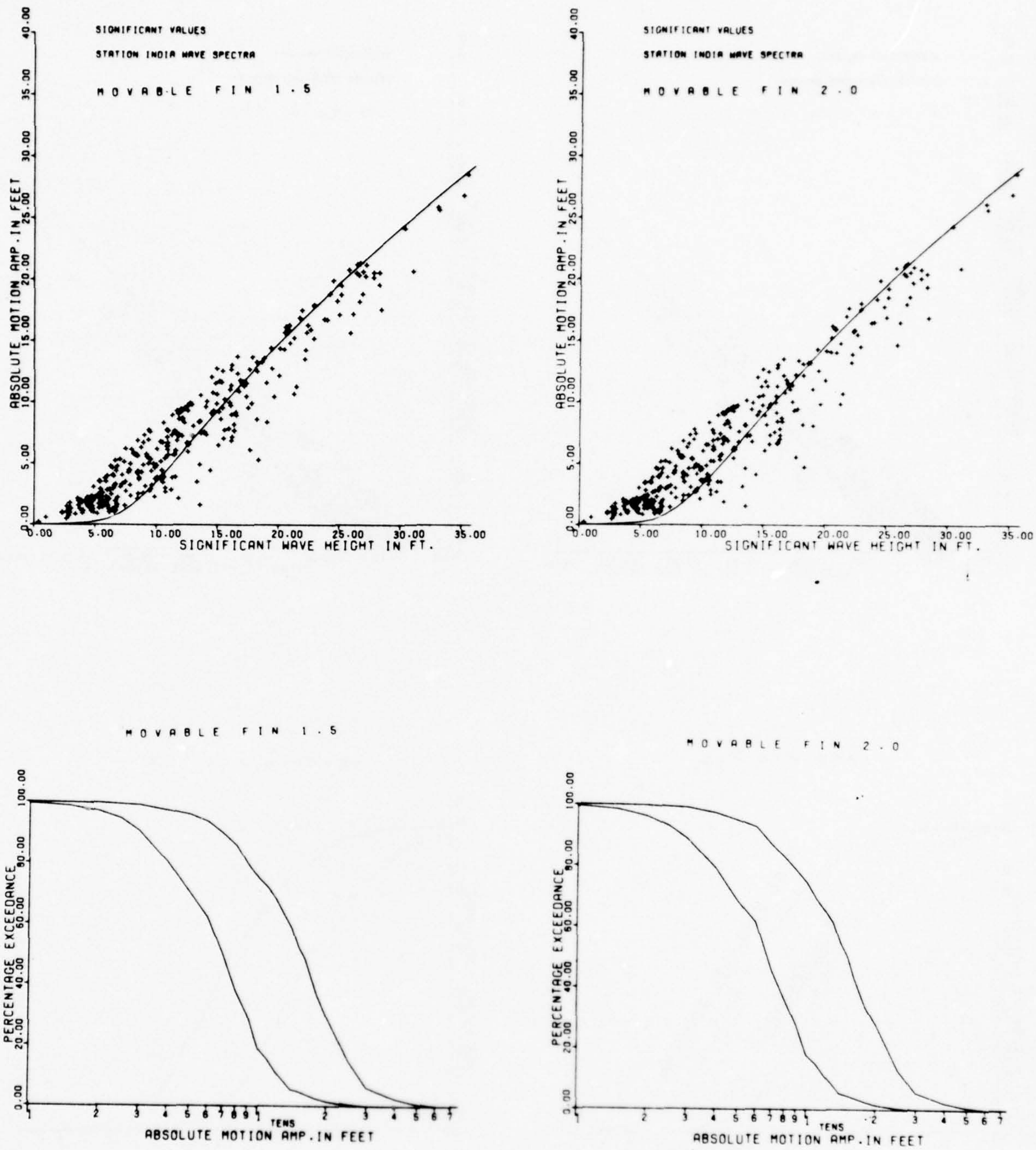


Figure 2 - continued

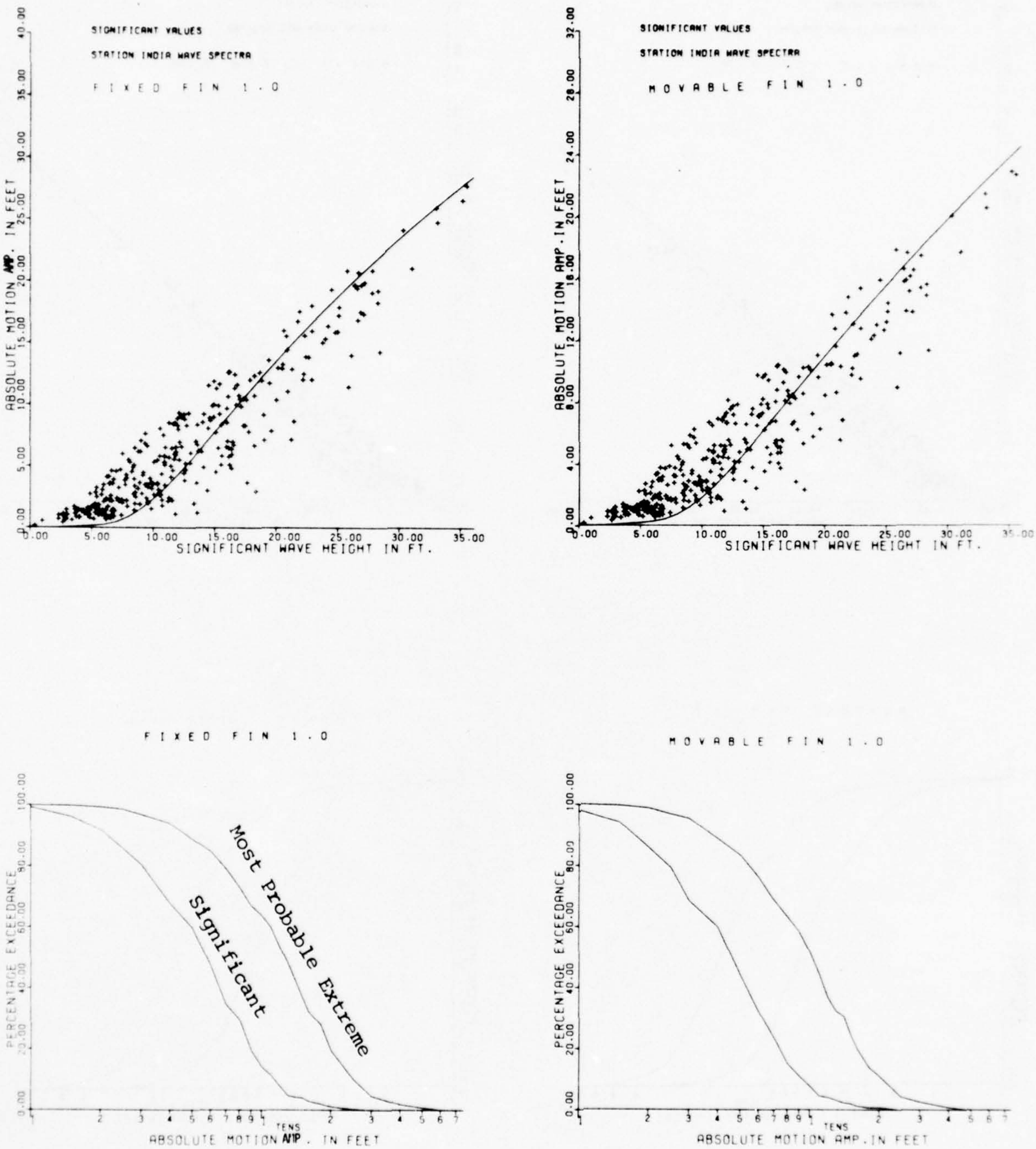


Figure 3 - Significant Amplitude of Vertical Motion and Percentage Exceedance at the Forward End of the Strut for 10 Knots with Various Fins

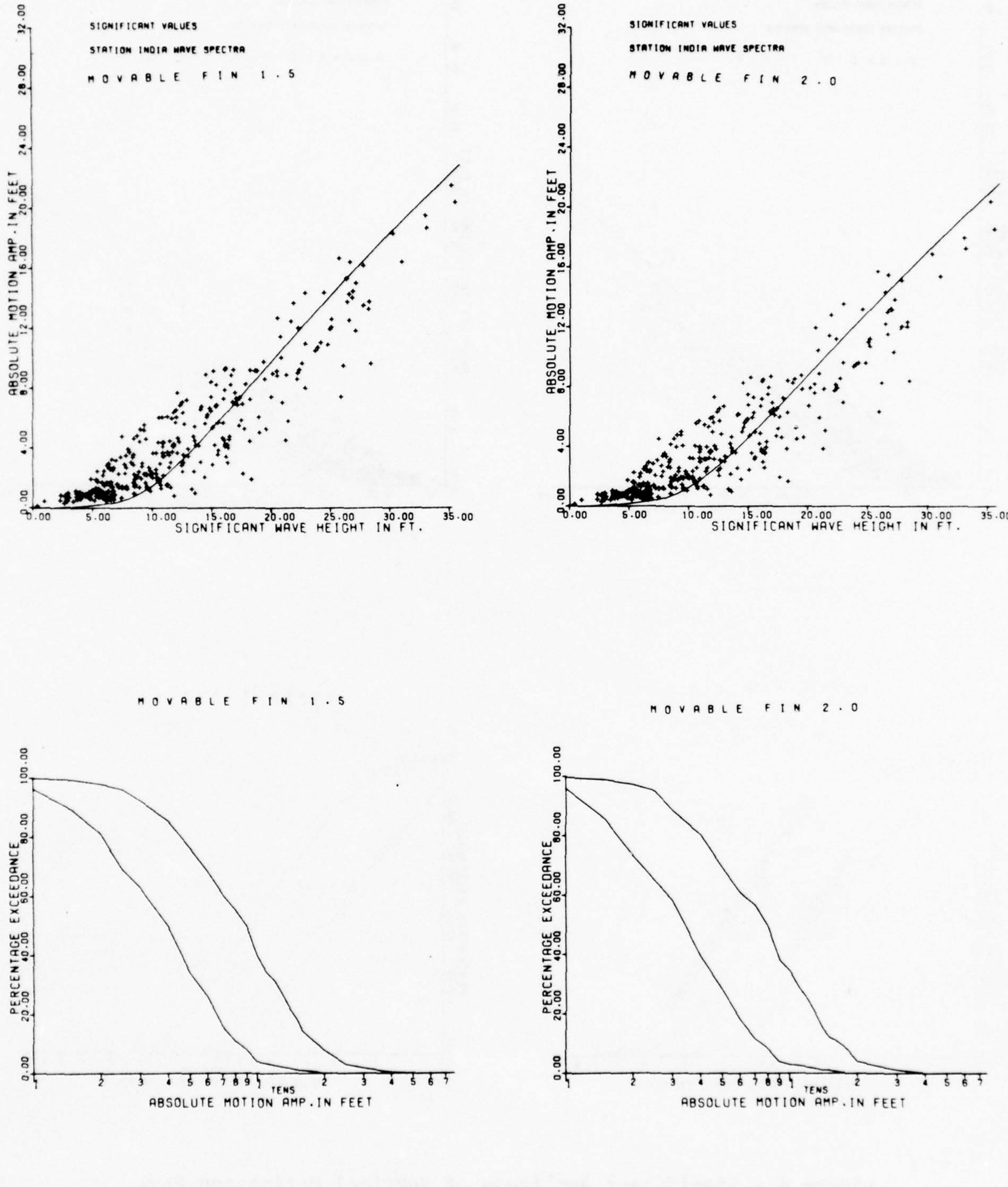


Figure 3 - continued

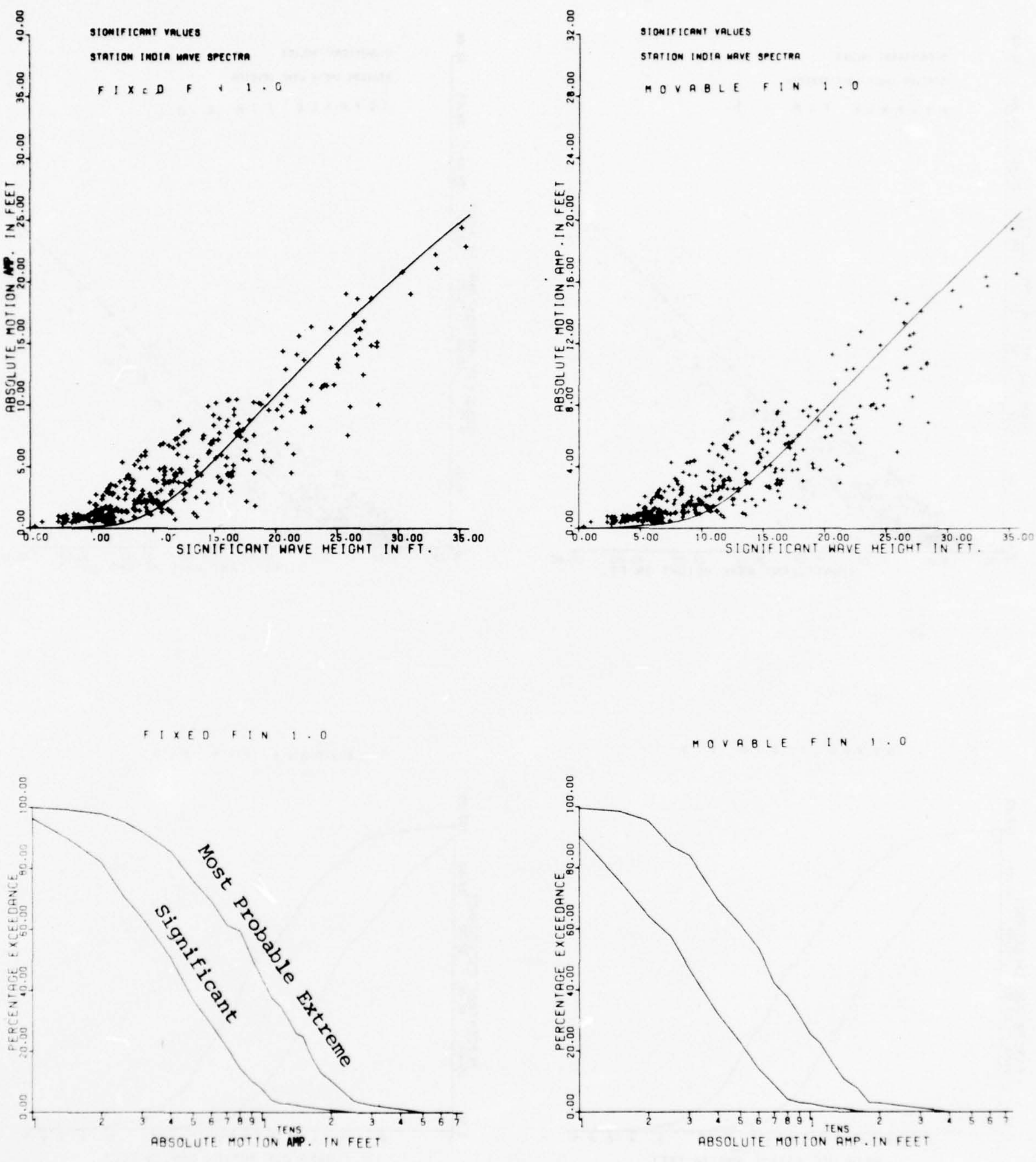


Figure 4 - Significant Amplitude of Vertical Motion and Percentage Exceedance at the Forward End of the Strut for 15 Knots with Various Fins

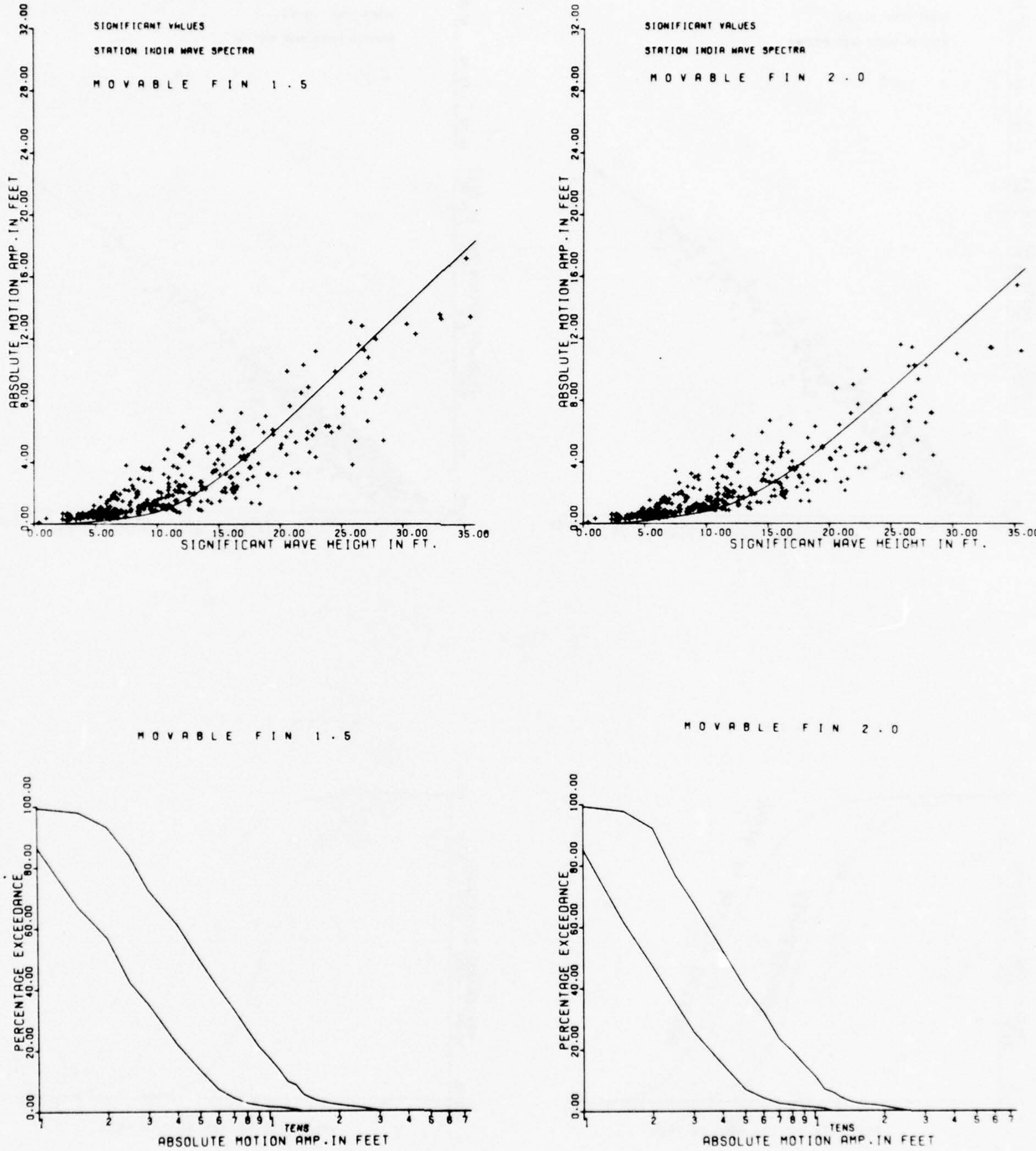


Figure 4 - continued

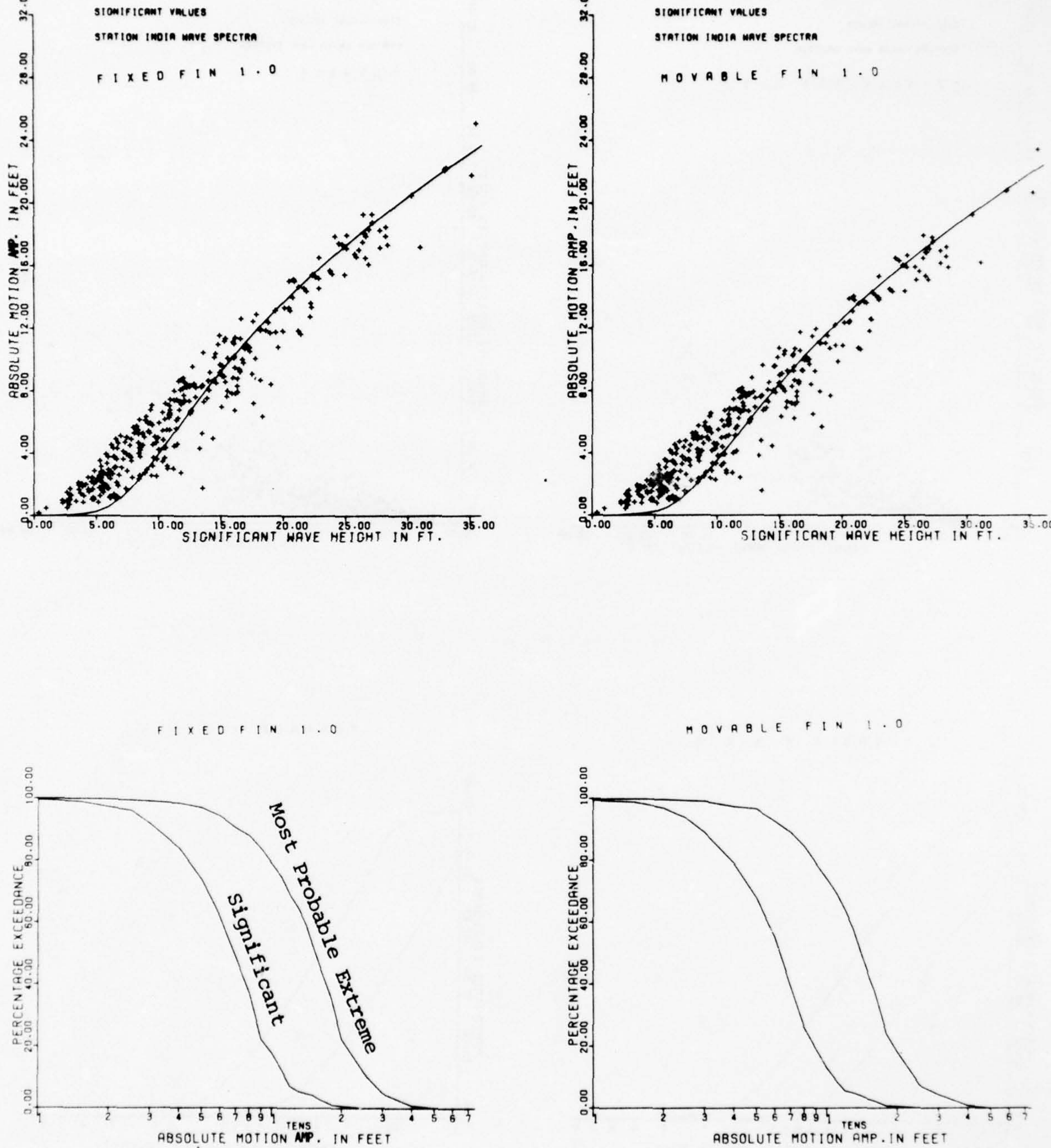


Figure 5 - Significant Amplitude of Heave and Percentage Exceedance for 5 Knots with Various Fins

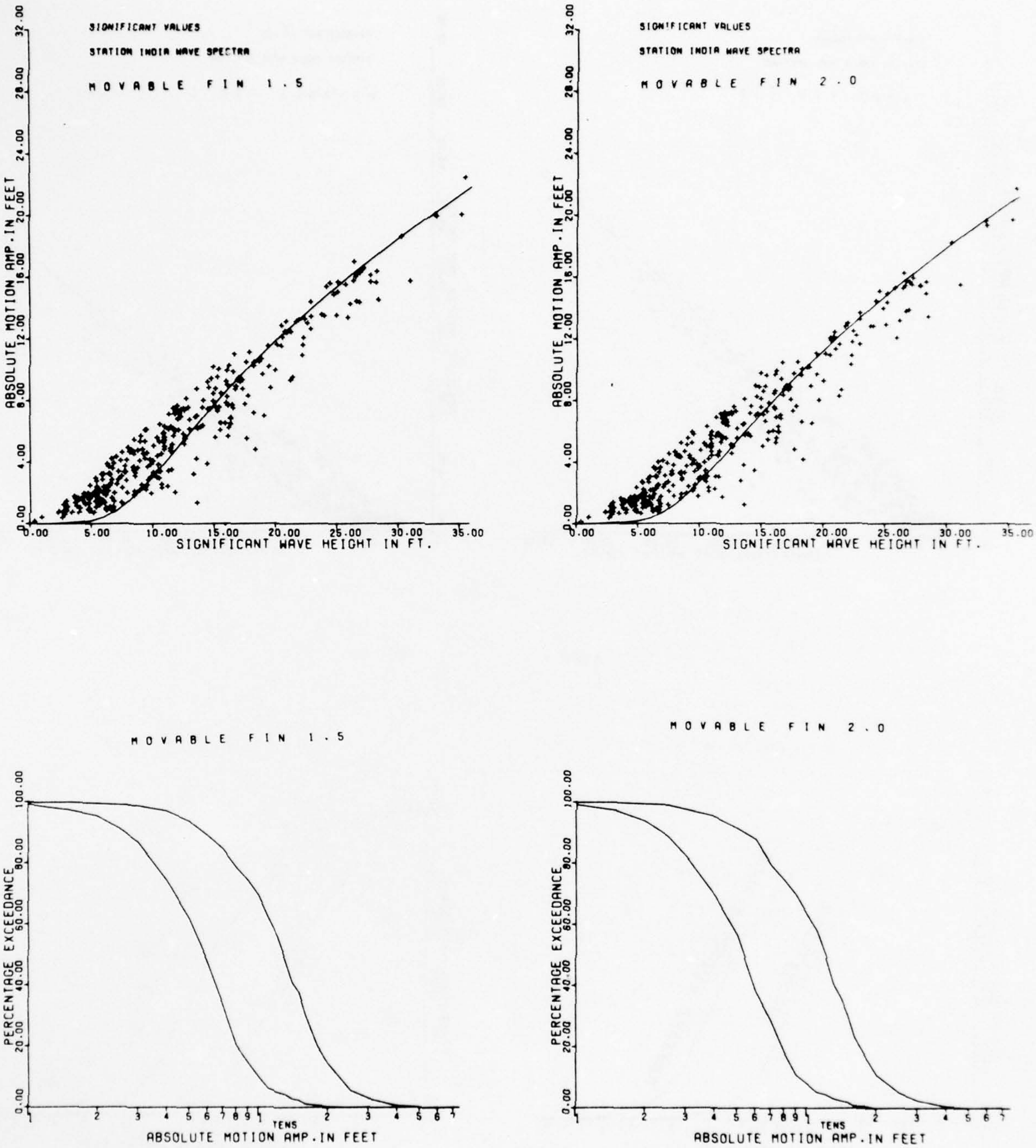


Figure 5 - continued

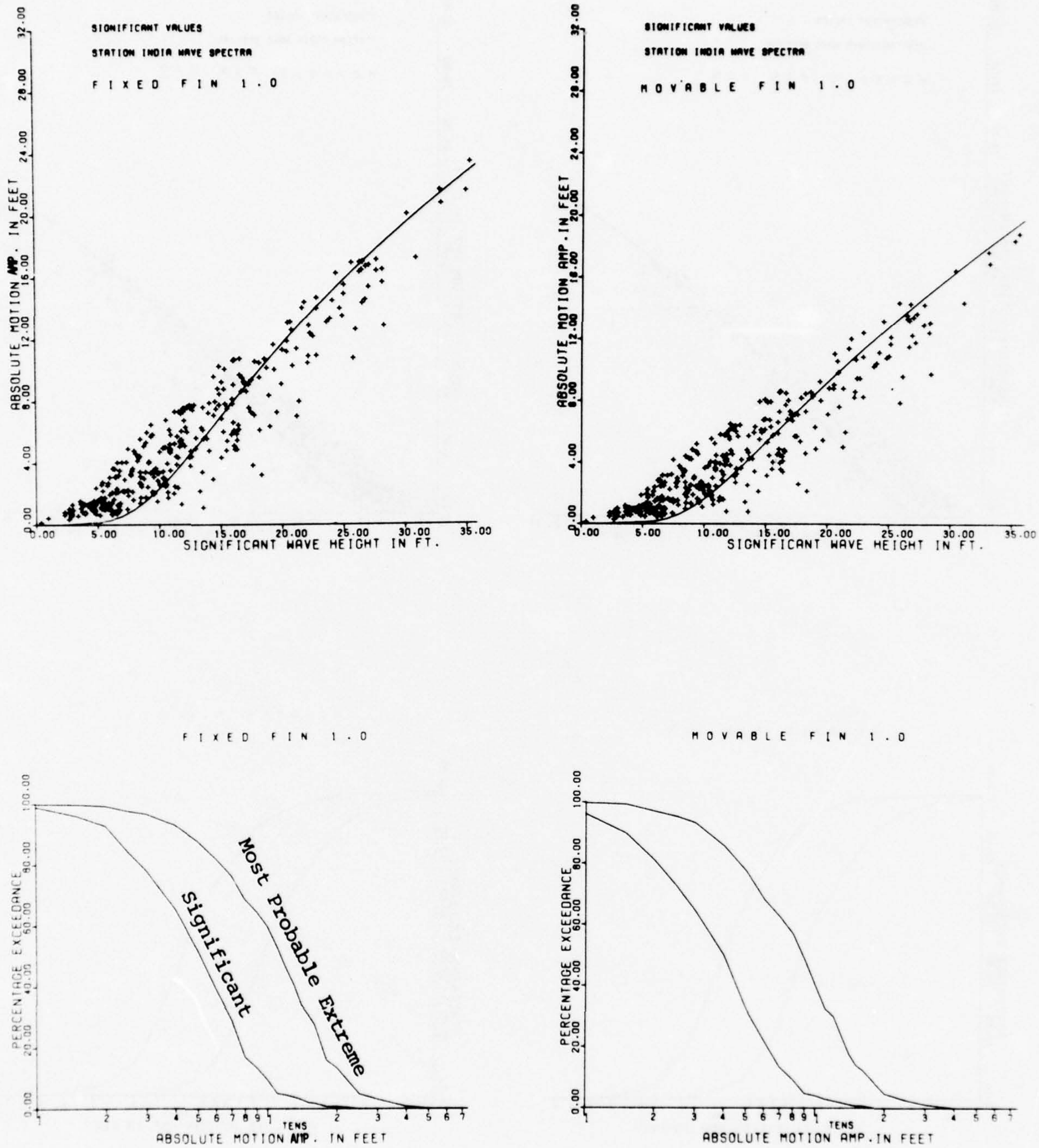


Figure 6 - Significant Amplitude of Heave and Percentage Exceedance for 10 Knots with Various Fins

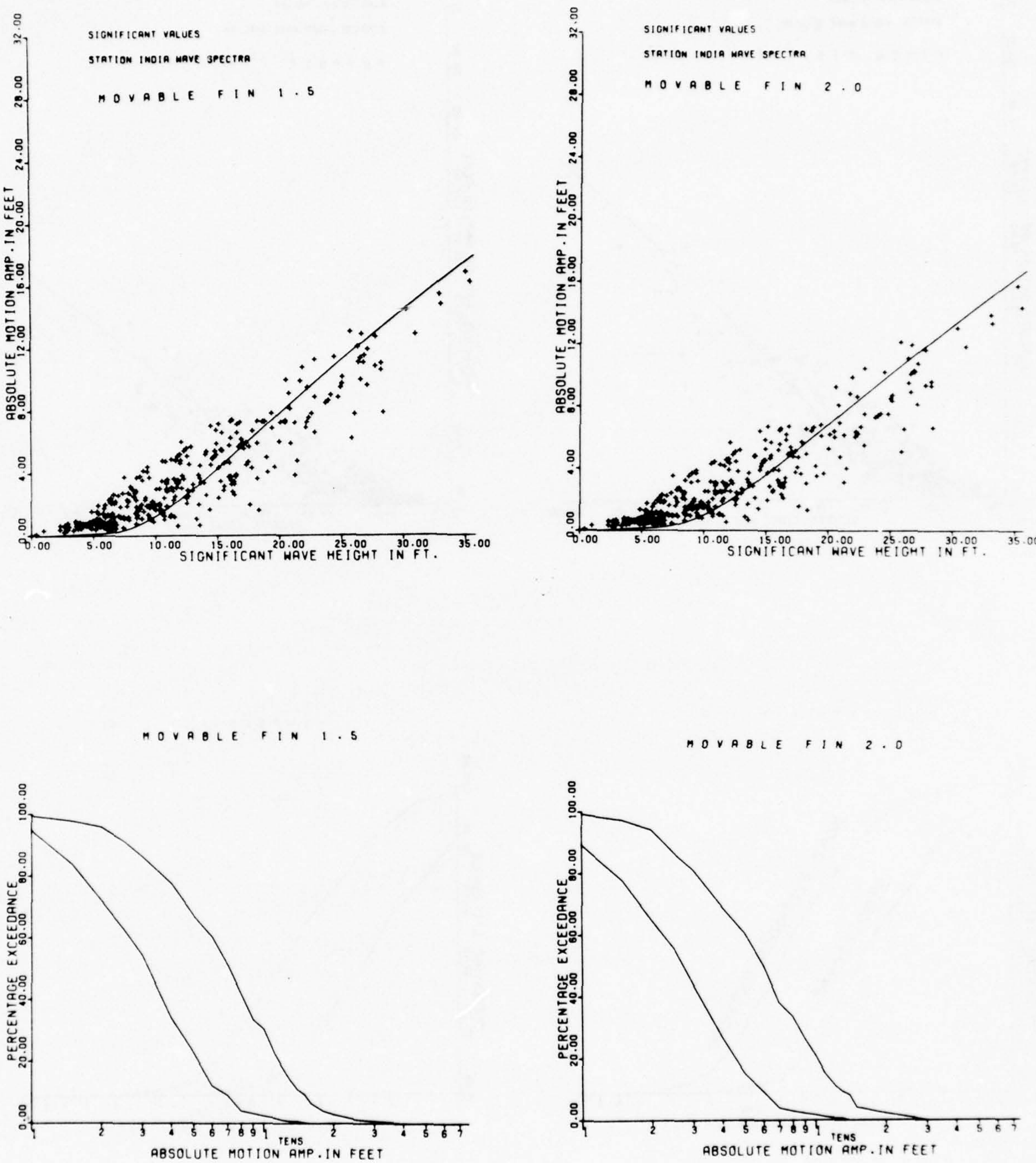


Figure 6 - continued

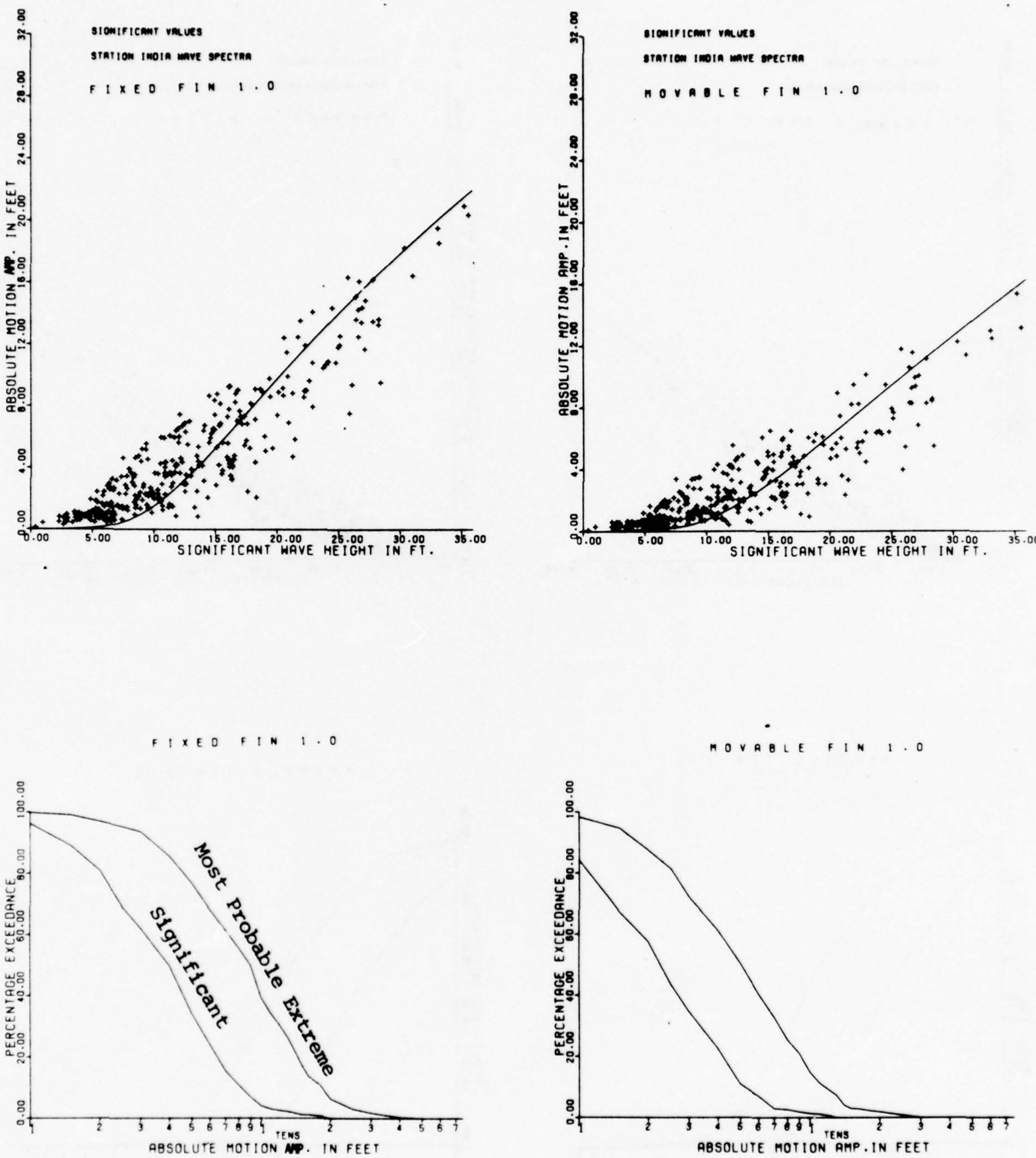
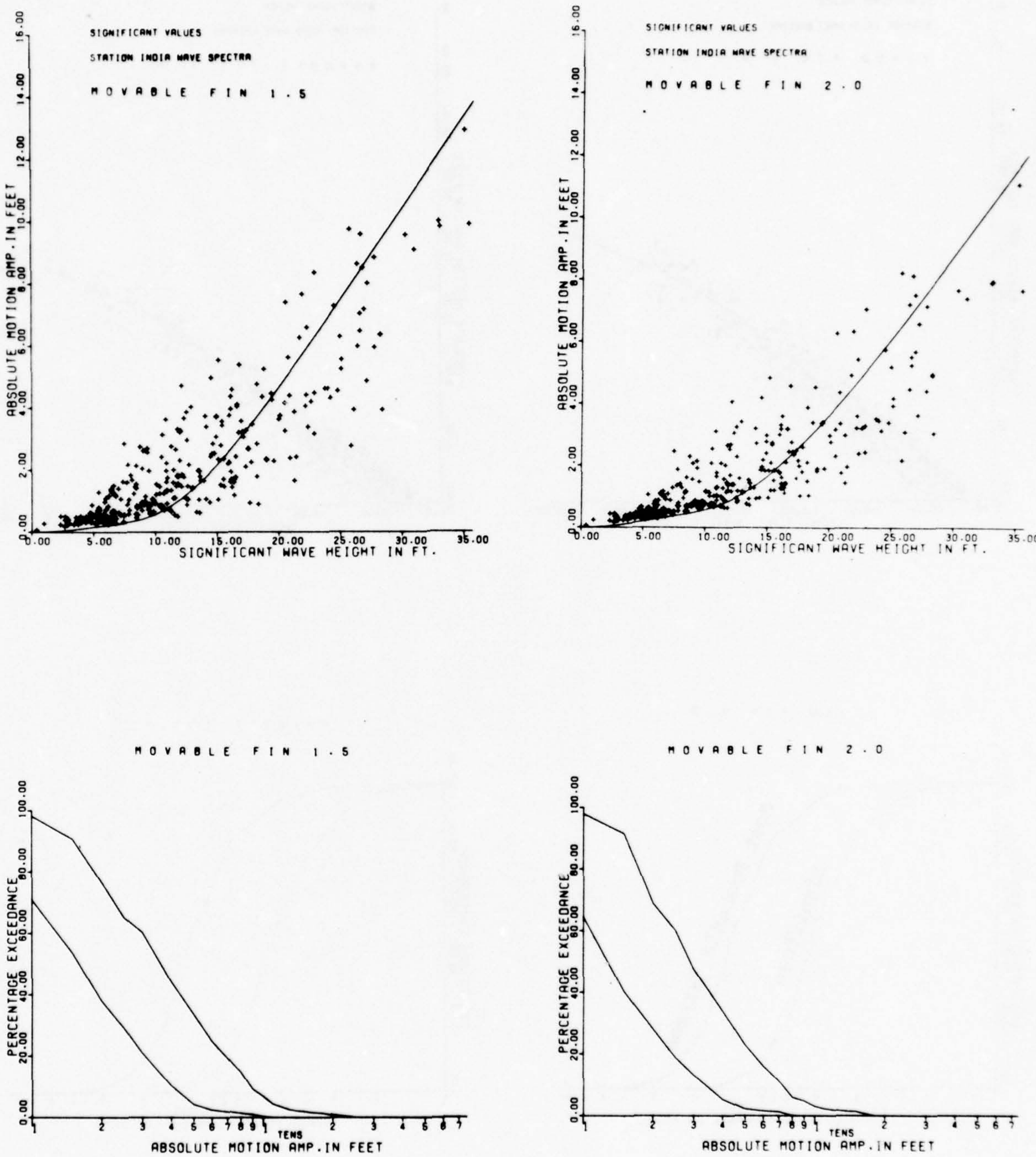


Figure 7 - Significant Amplitude of Heave and Percentage Exceedance for 15 Knots with Various Fins



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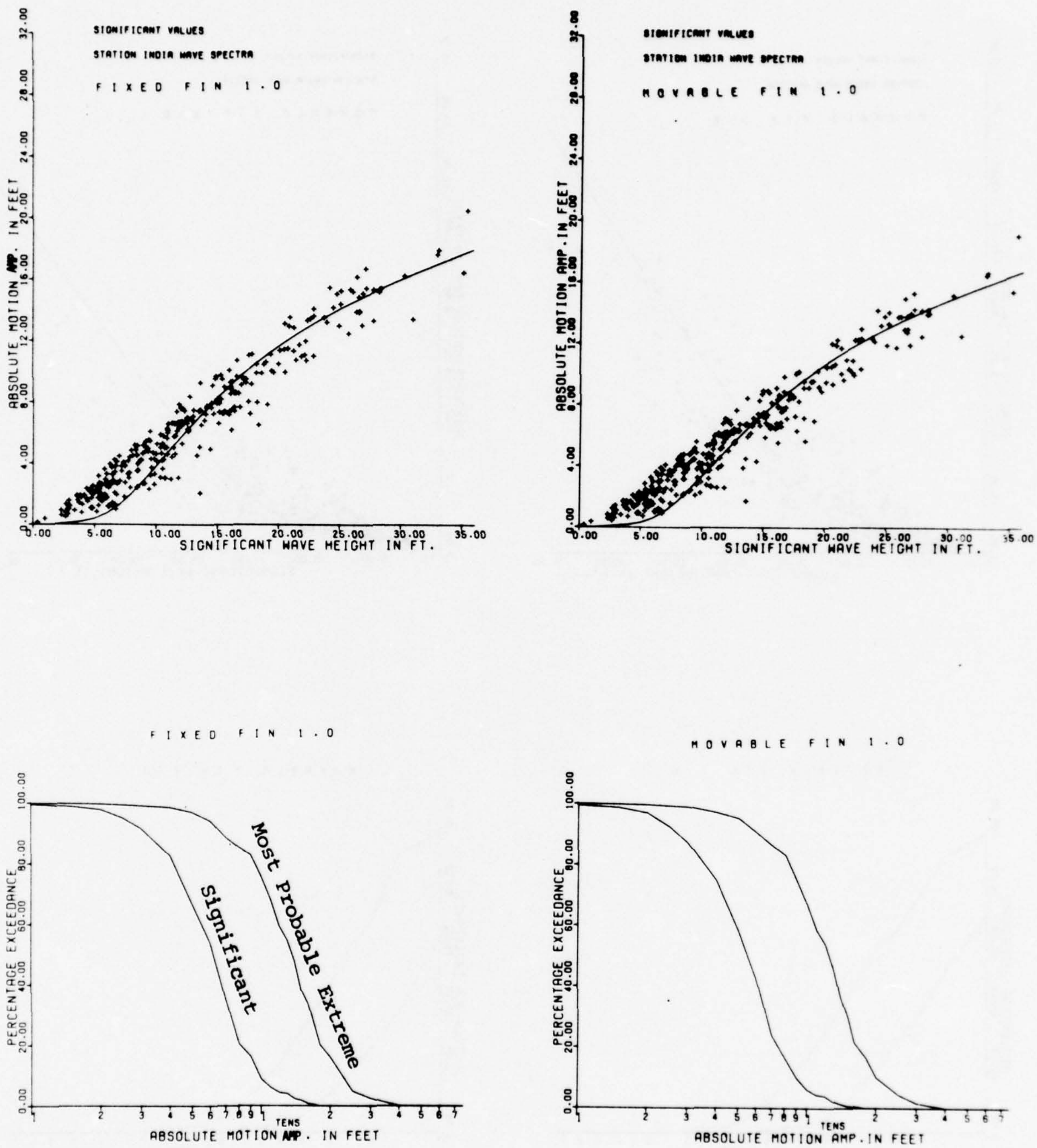
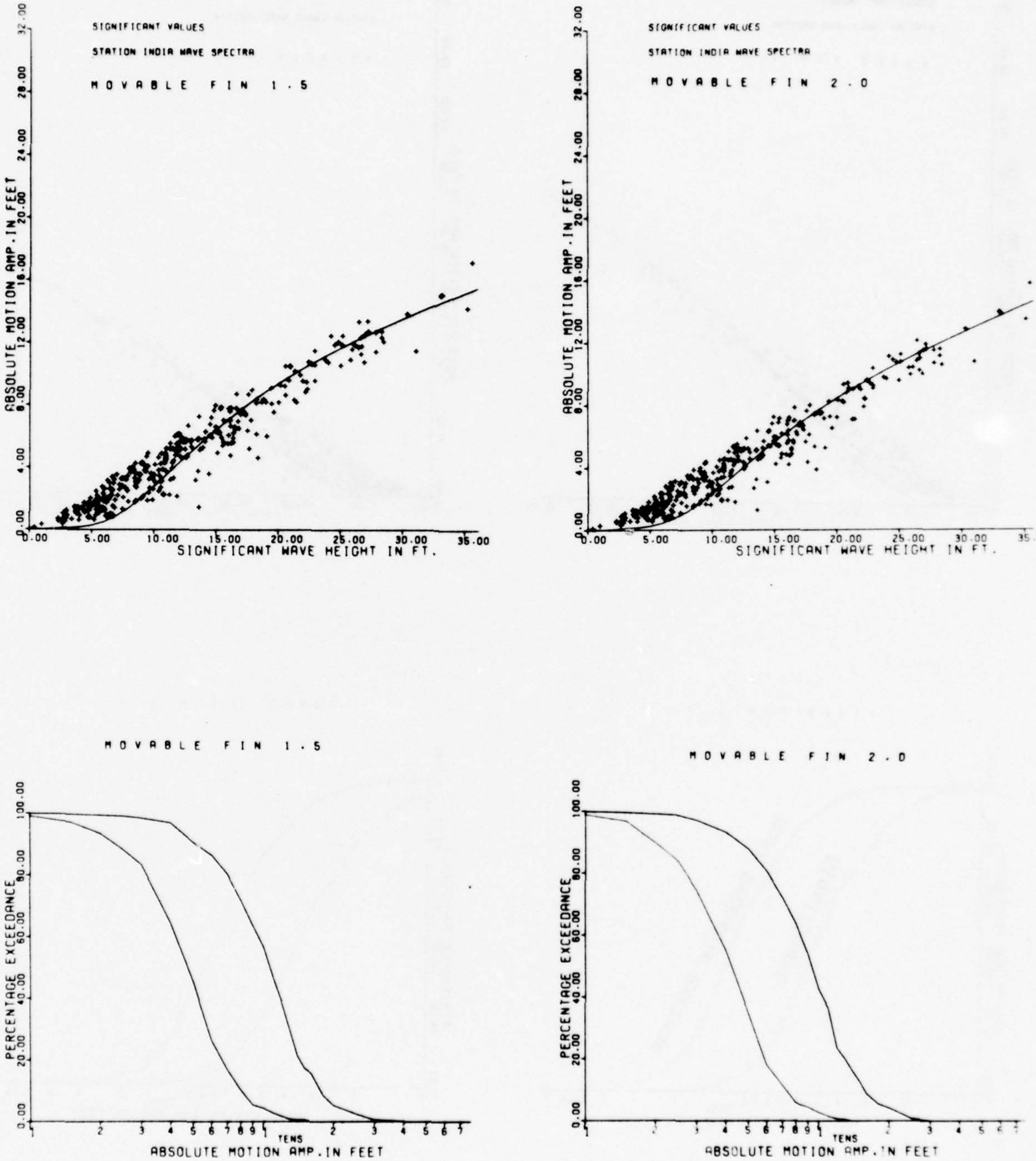


Figure 8 - Significant Amplitude of Vertical Motion and Percentage Exceedance at the Aft End of the Strut for 5 Knots with Various Fins



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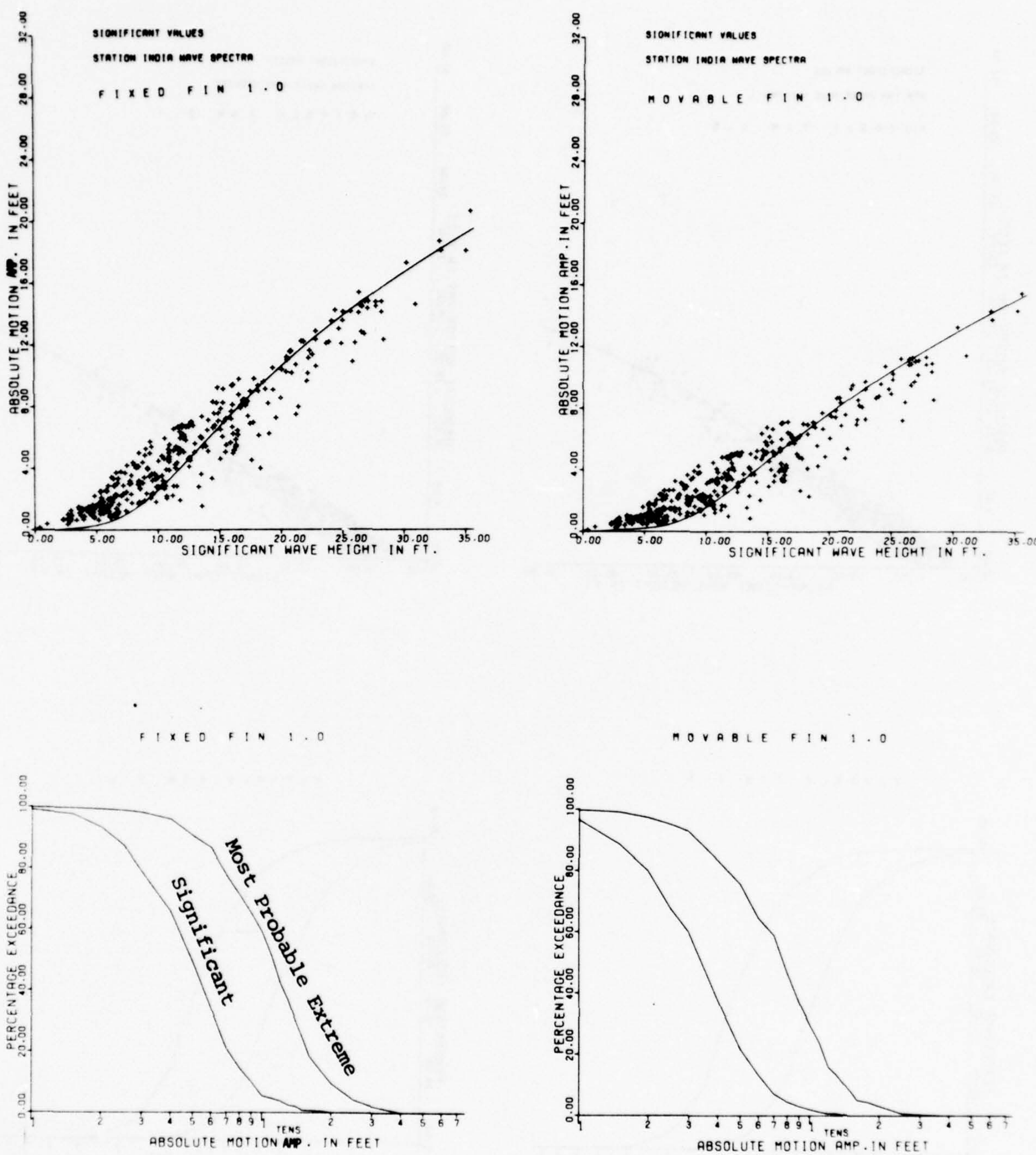
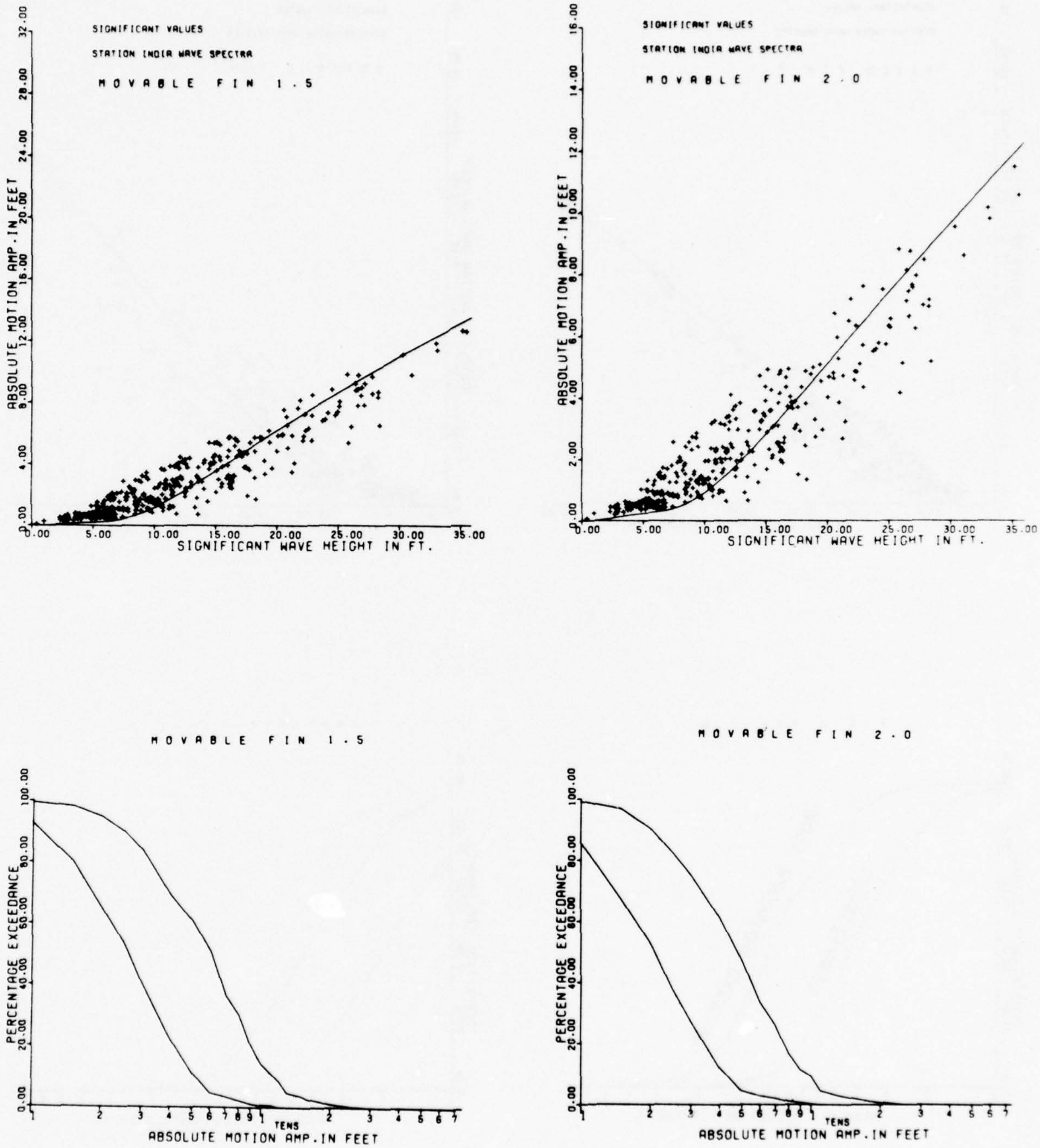


Figure 9 - Significant Amplitude of Vertical Motion and Percentage Exceedance at the Aft End of the Strut for 10 Knots with Various Fins



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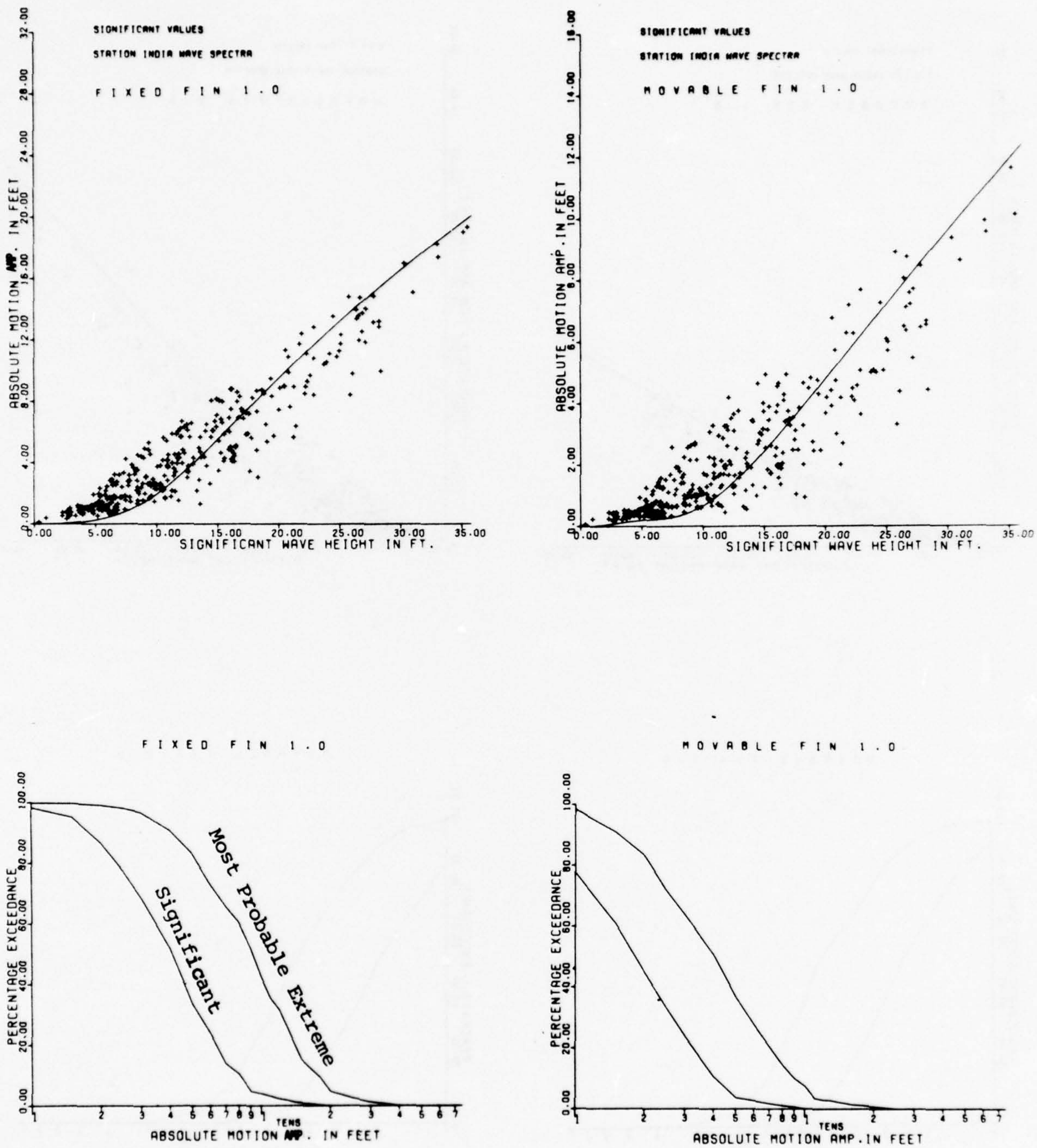


Figure 10 - Significant Amplitude of Vertical Motion and Percentage Exceedance at the Aft End of the Strut for 15 Knots with Various Fins

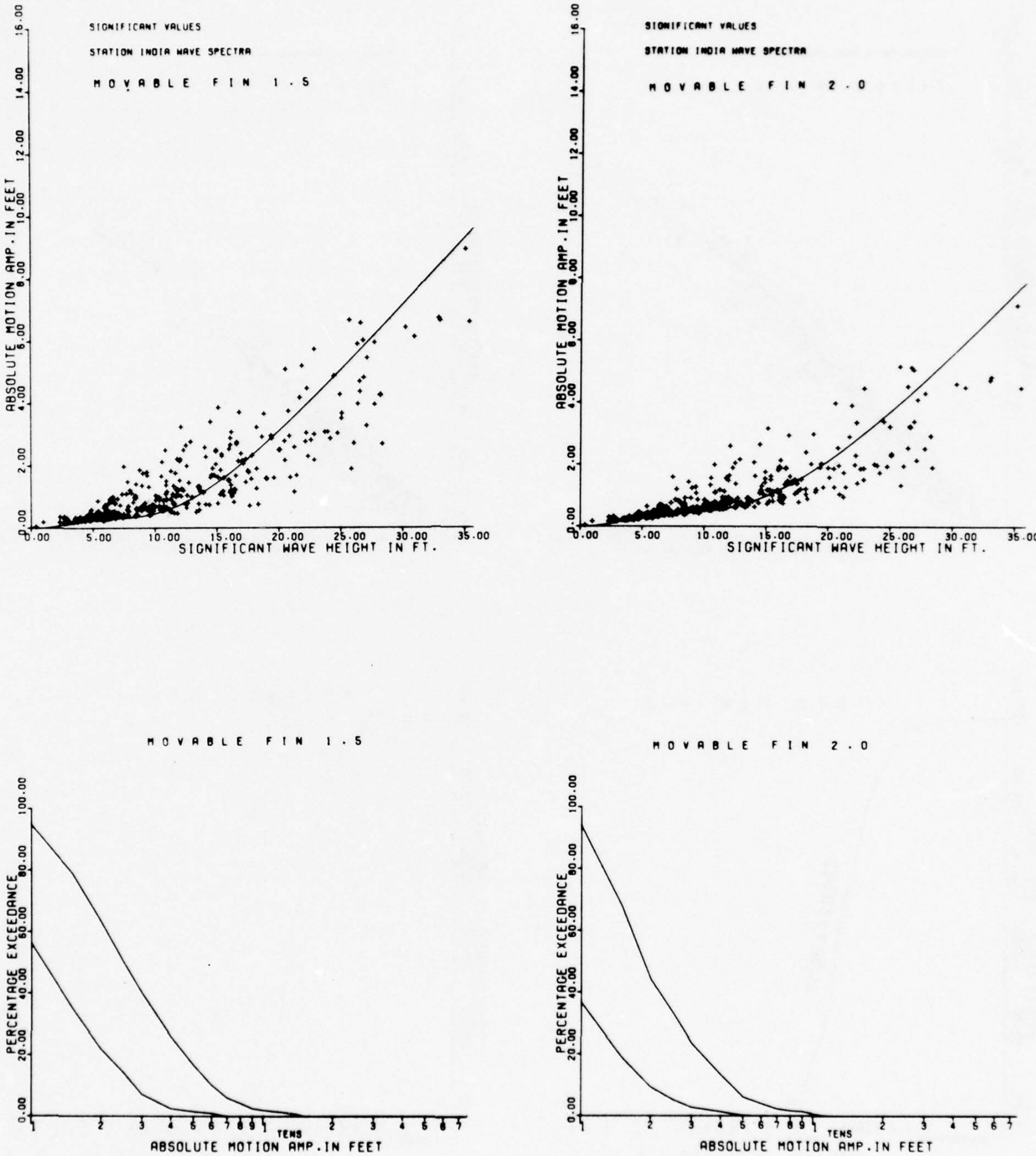


Figure 10 - continued

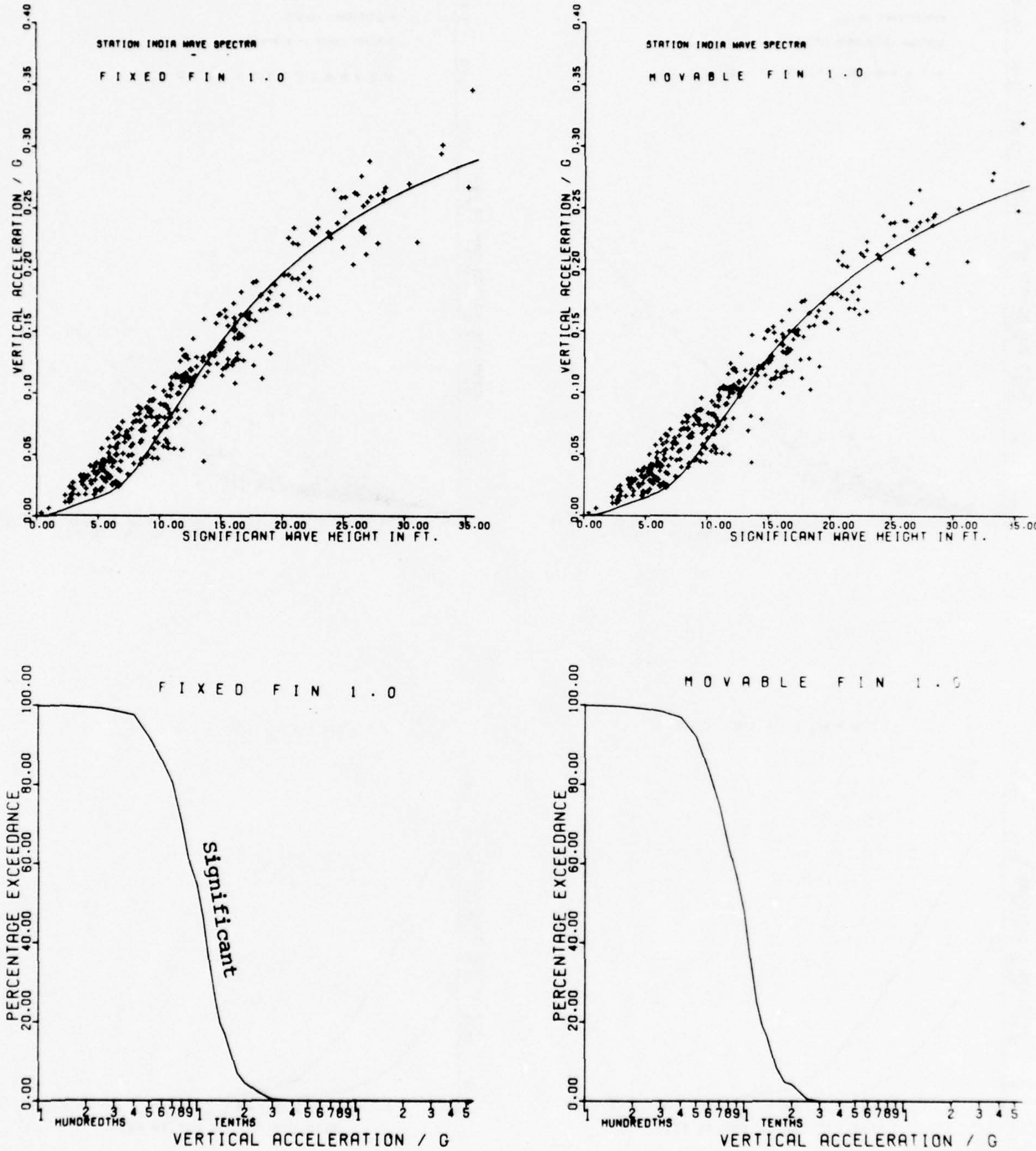


Figure 11 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Forward End of the Strut for 5 Knots with Various Fins

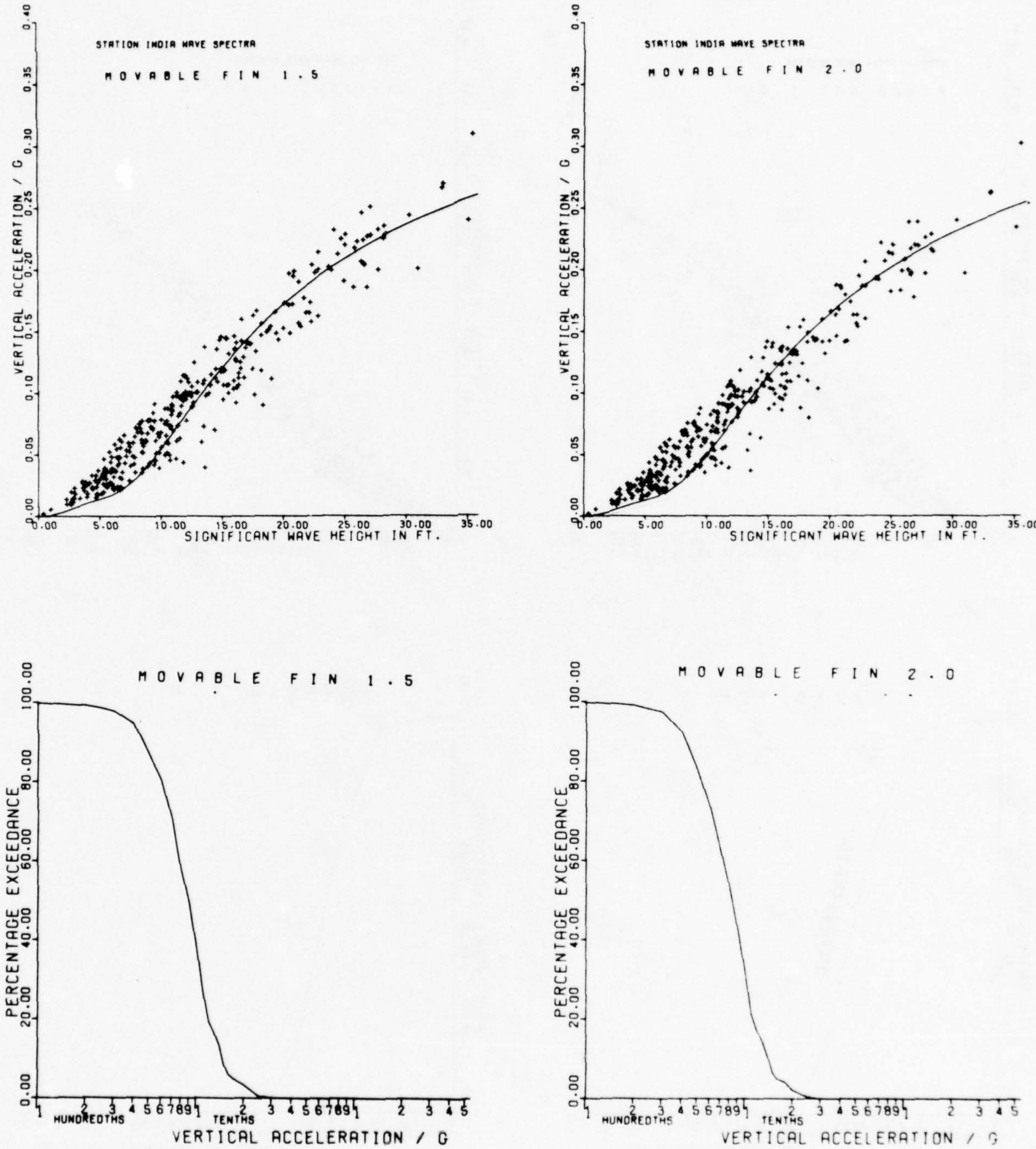


Figure 11 - continued

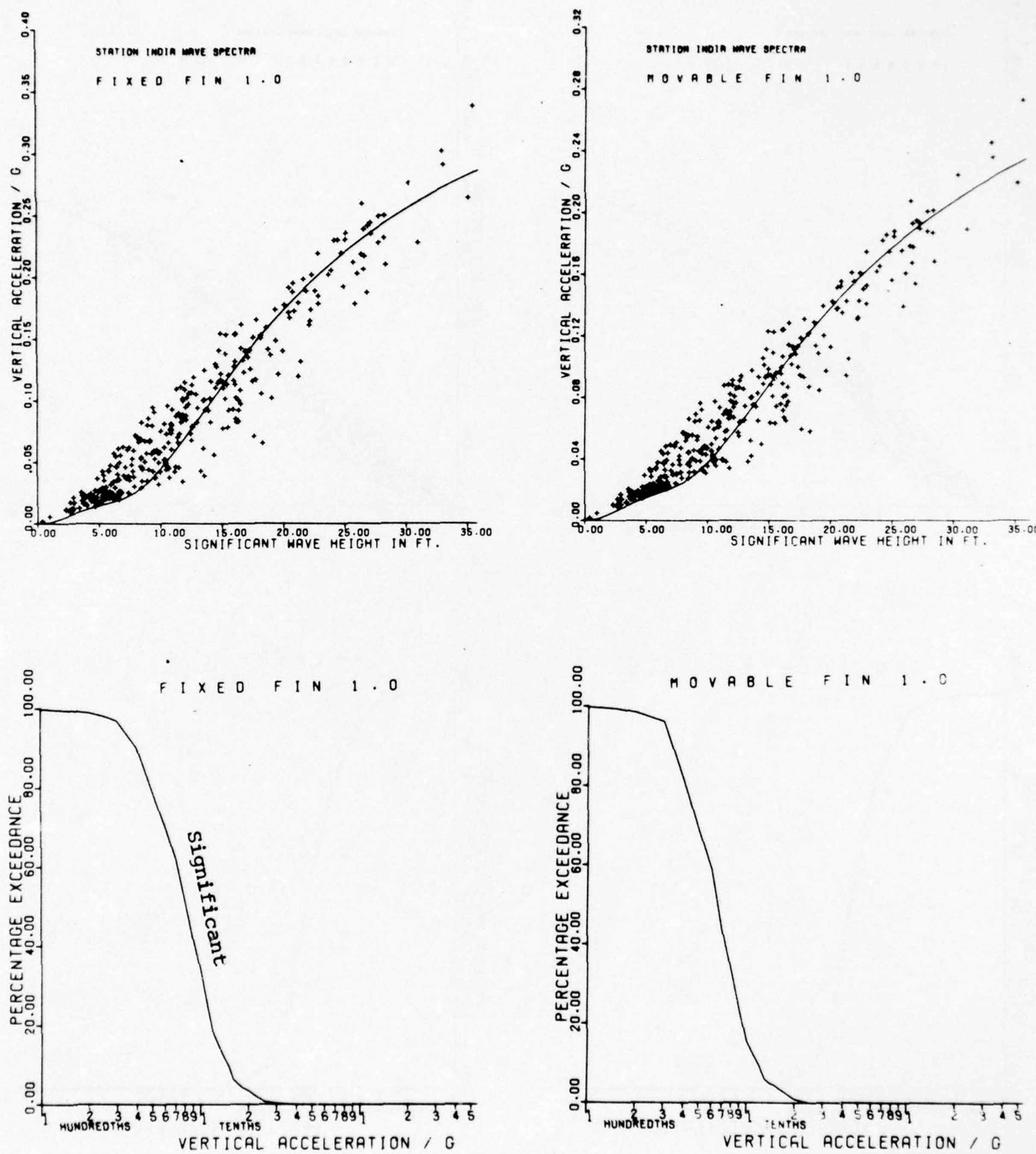


Figure 12 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Forward End of the Strut for 10 Knots with Various Fins

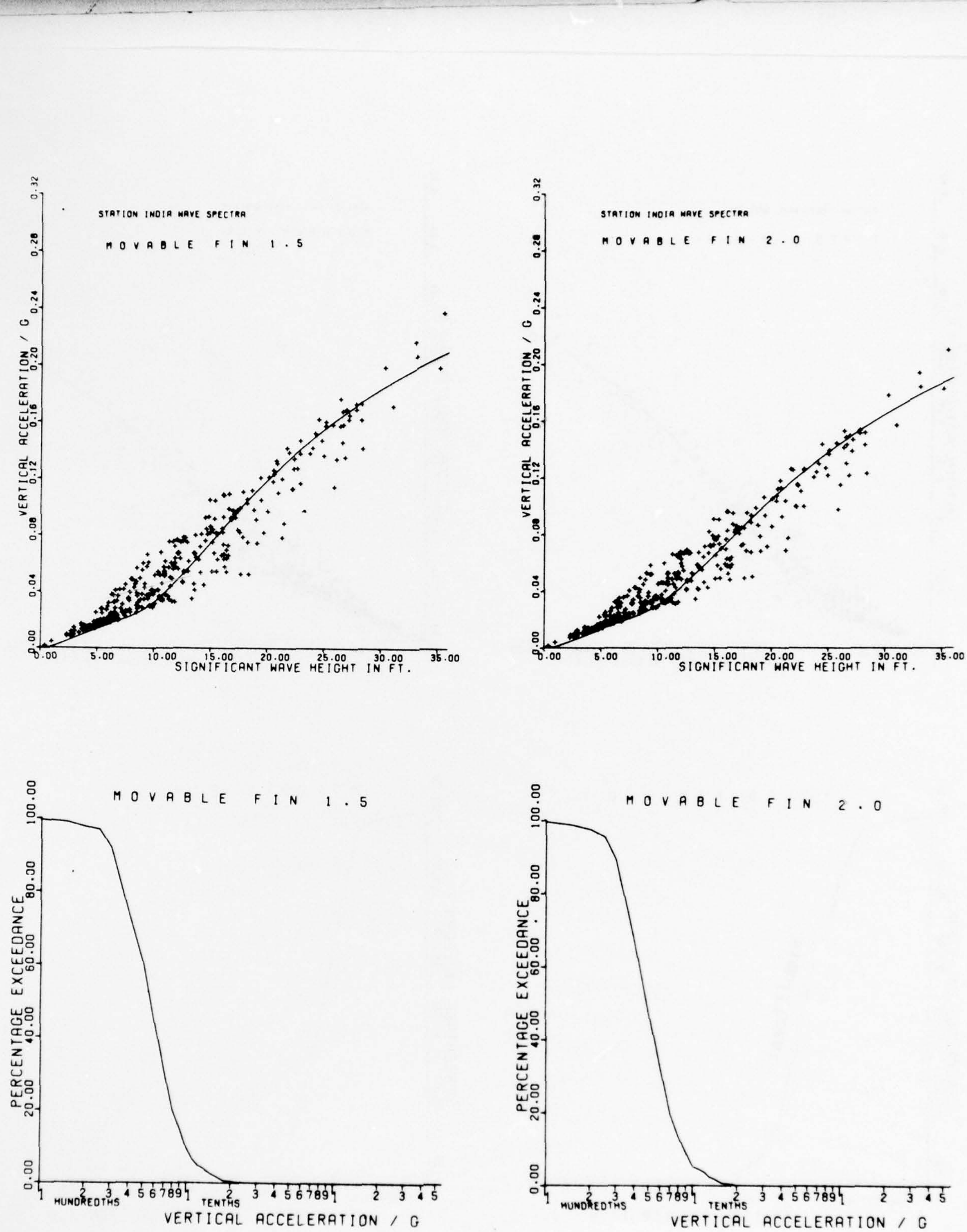


Figure 12 - continued

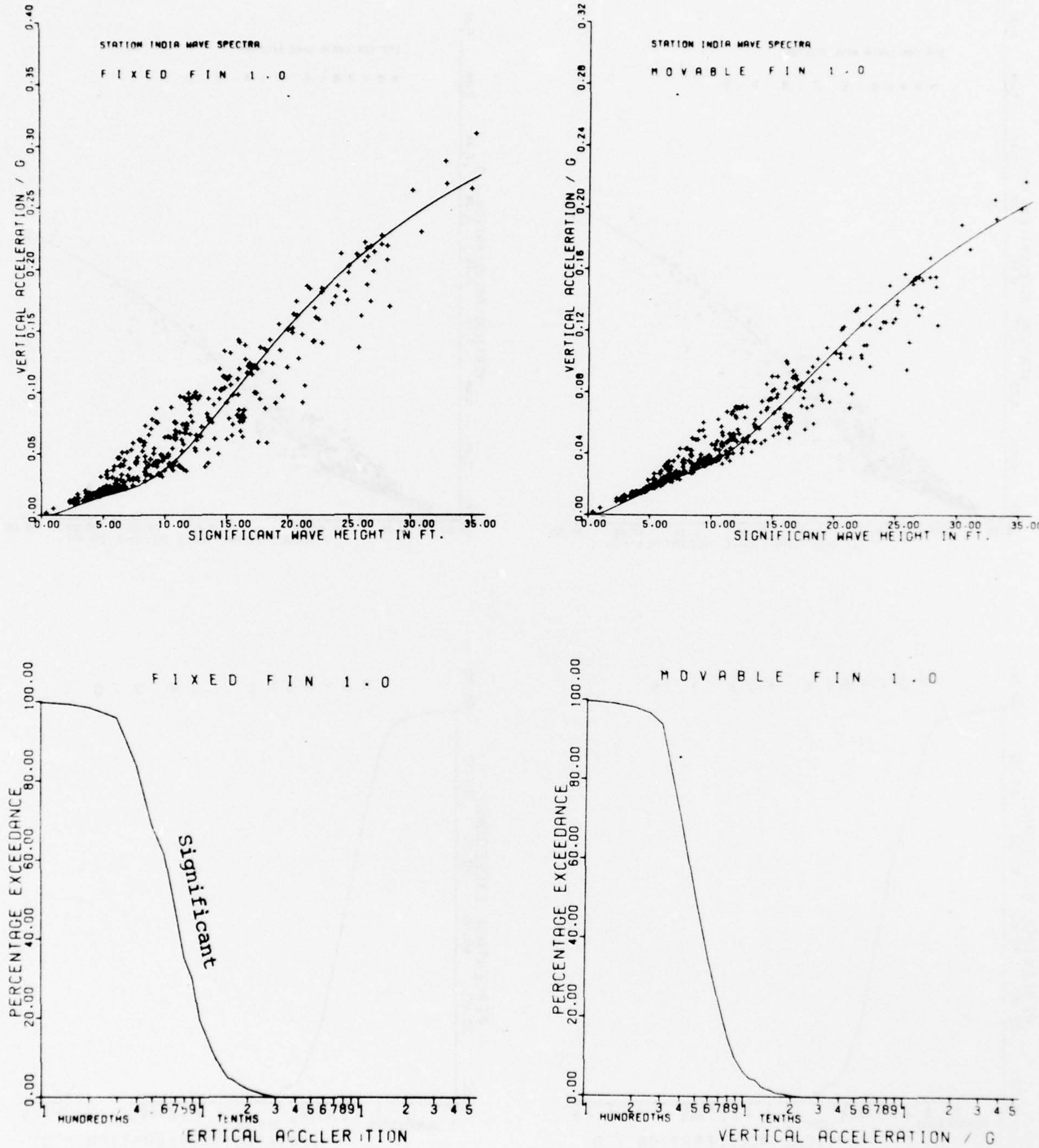
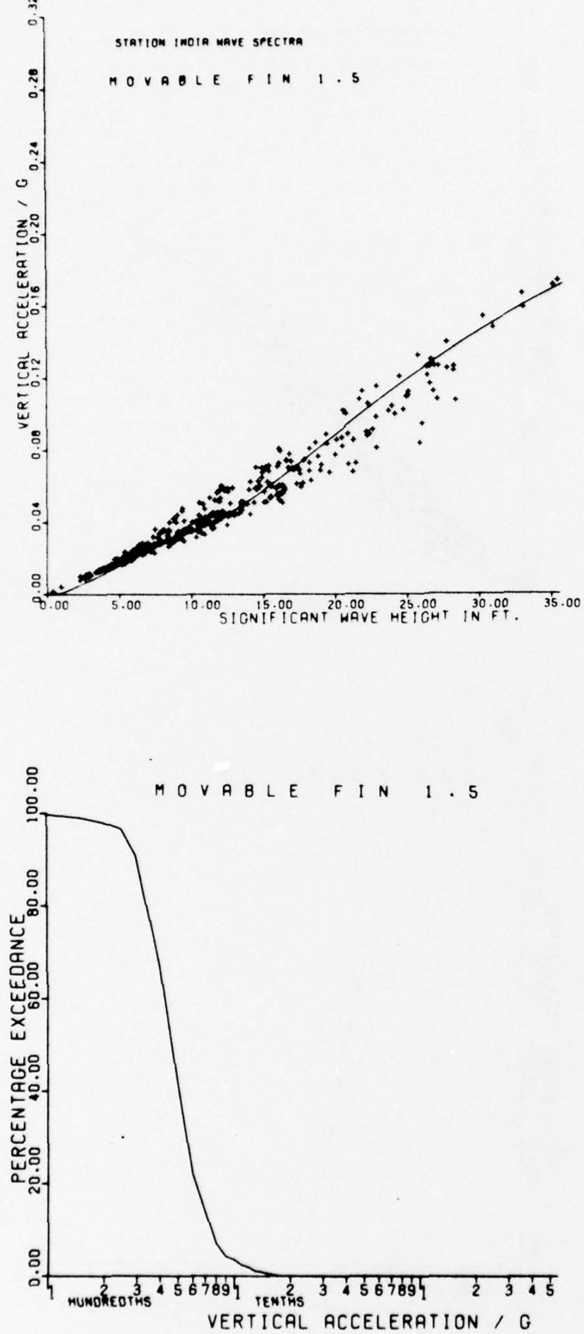


Figure 13 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Forward End of the Strut for 15 Knots with Various Fins



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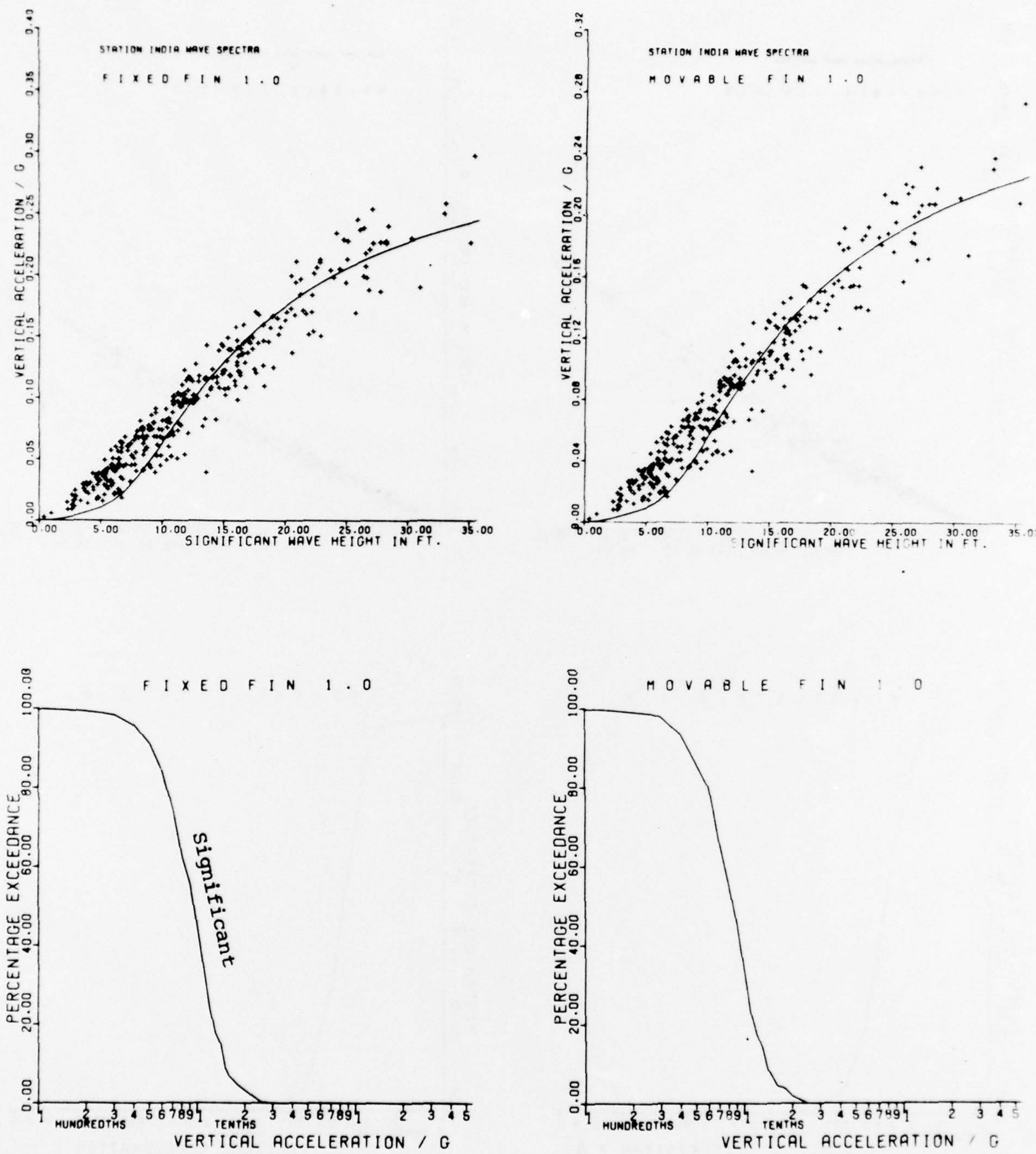

Figure 14 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Center of Gravity for 5 Knots with Various Fins

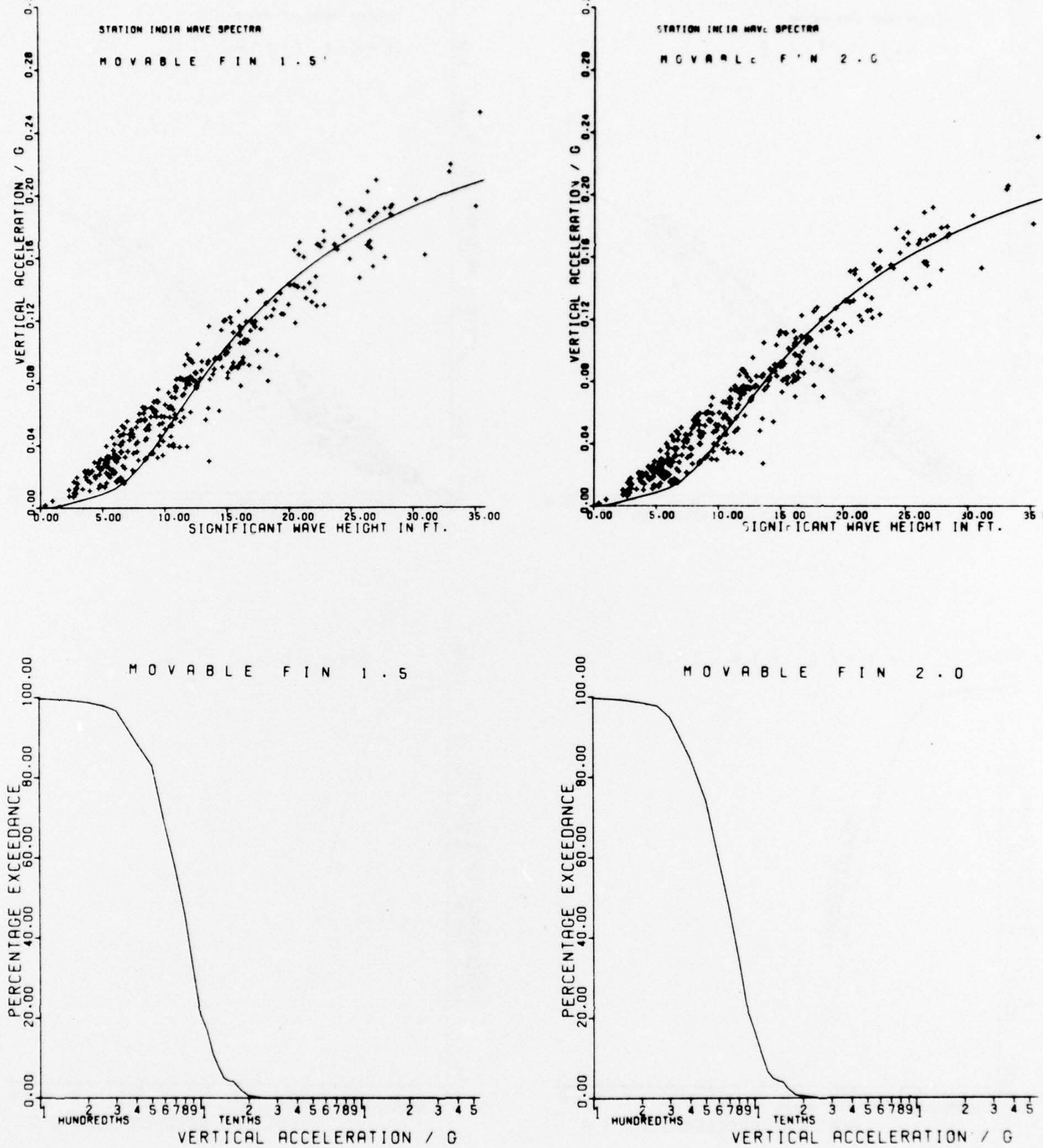

Figure 14 - continued

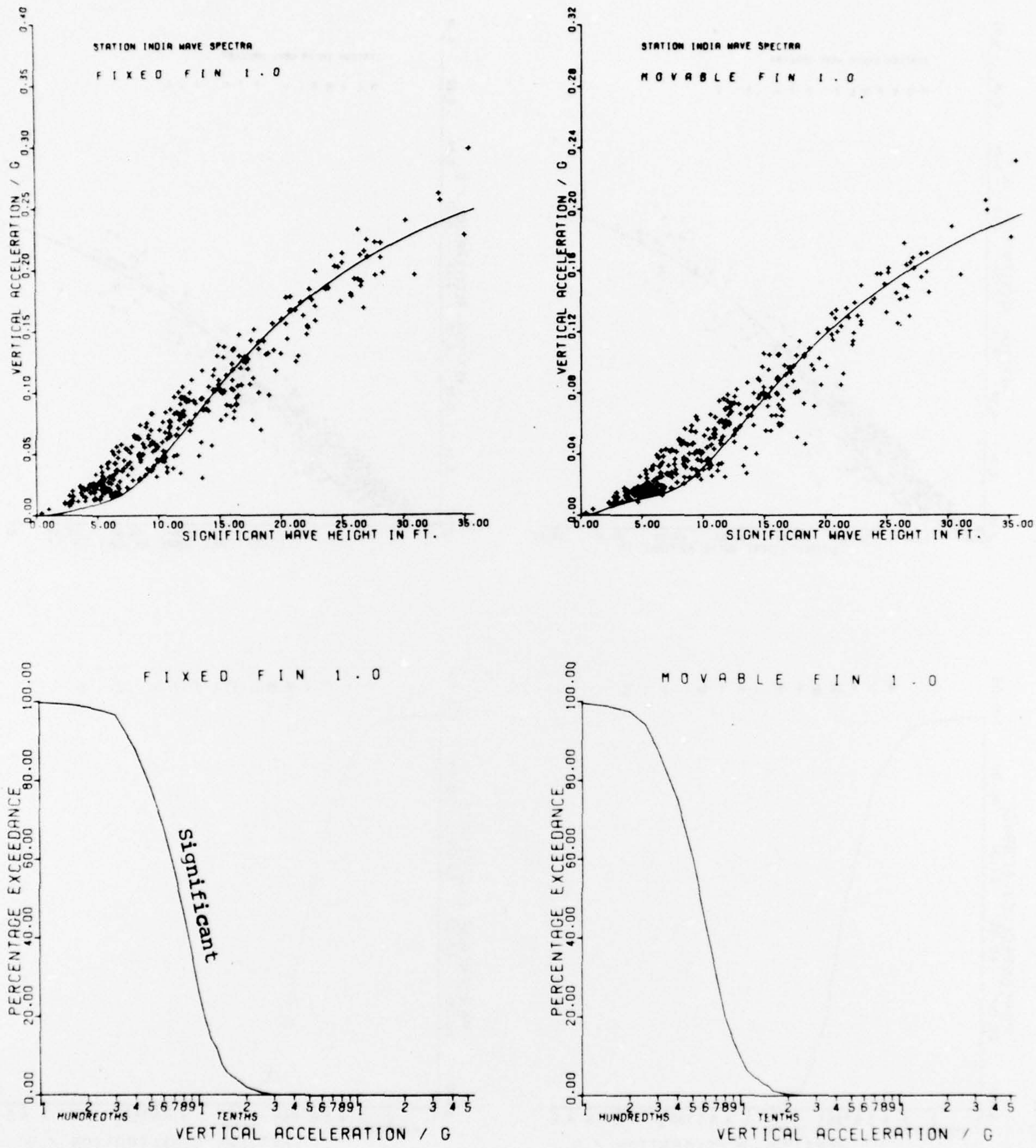

Figure 15 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Center of Gravity for 10 Knots with Various Fins

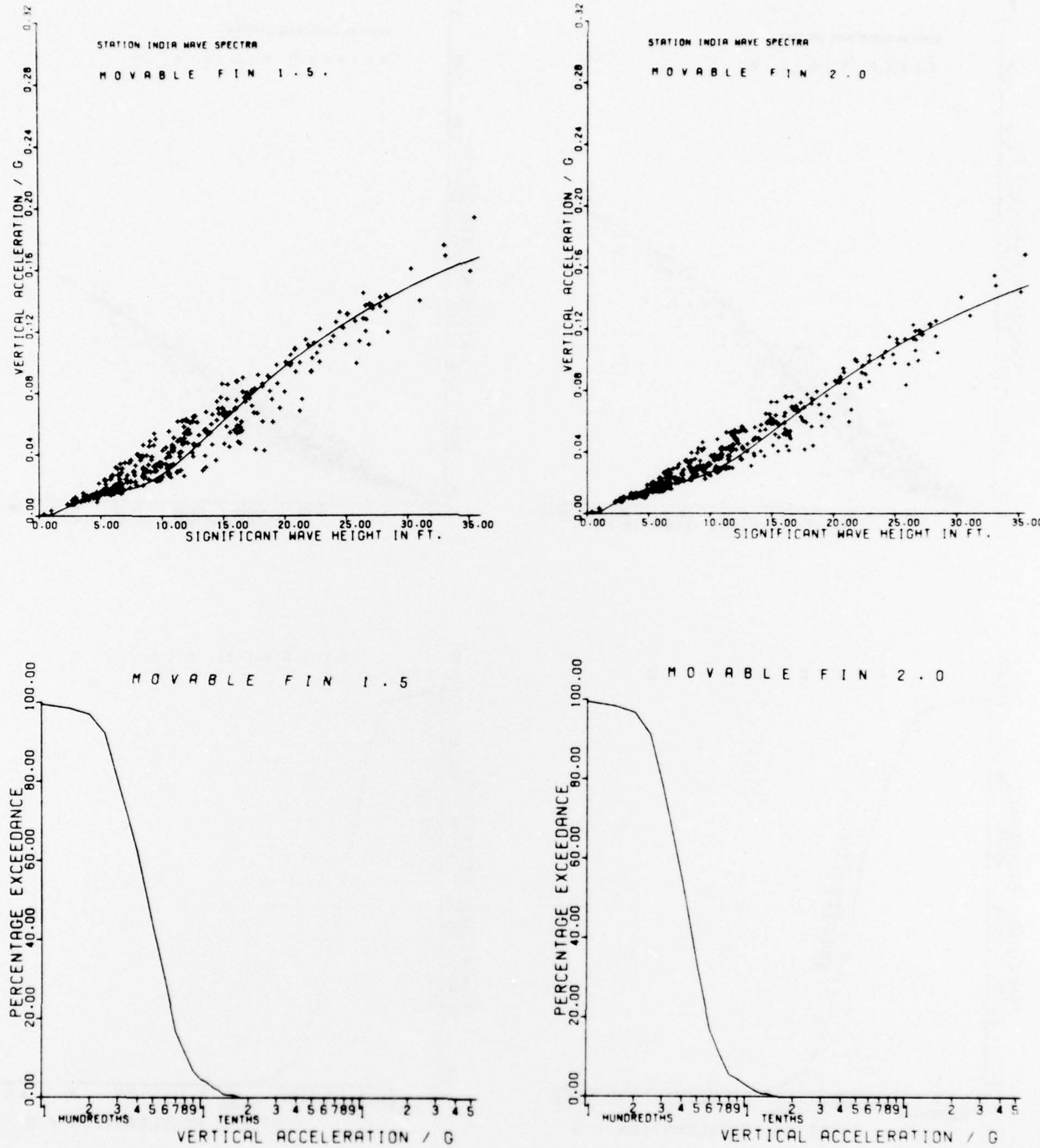

Figure 15 - continued

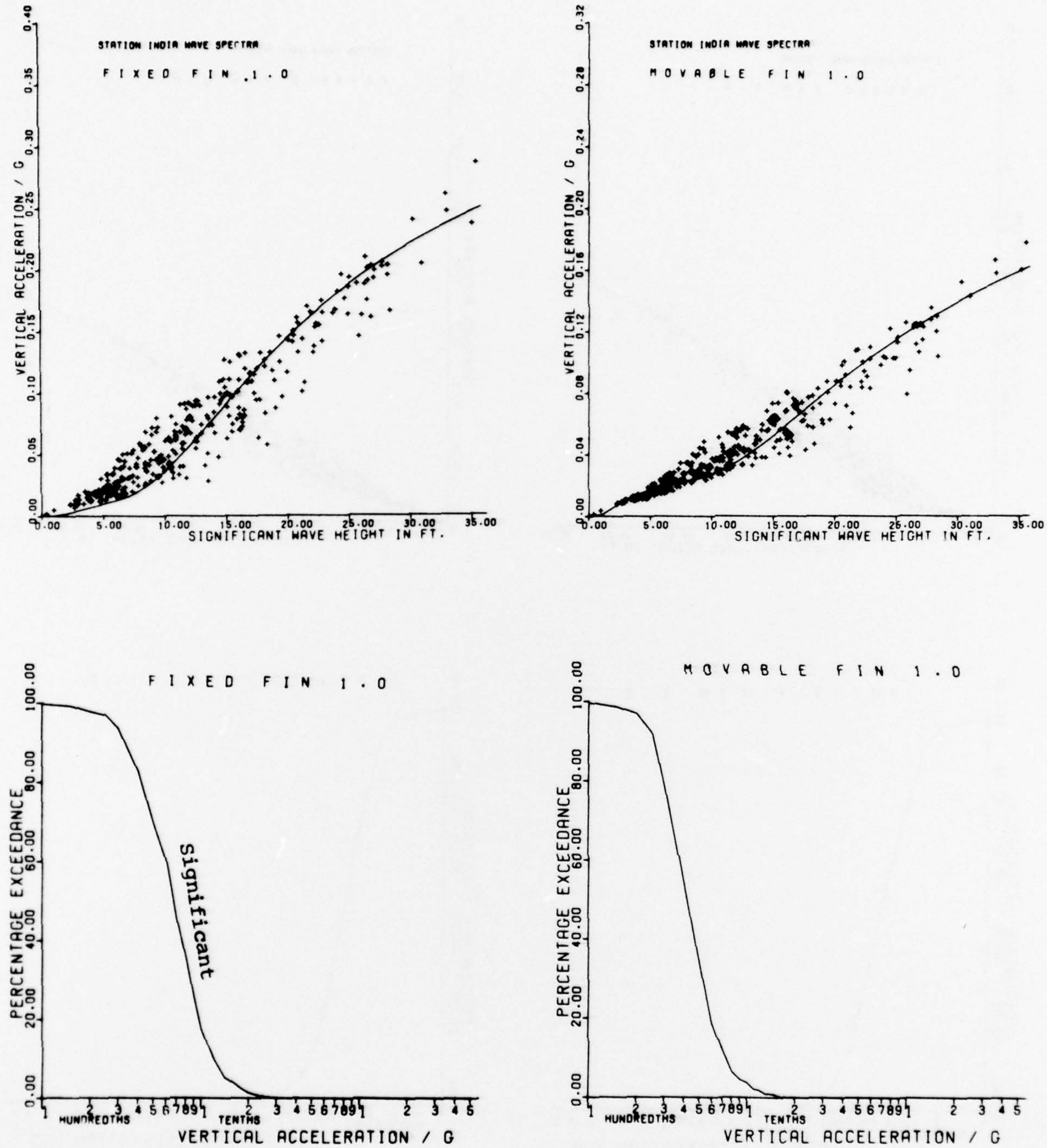

Figure 16 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Center of Gravity for 15 Knots with Various Fins

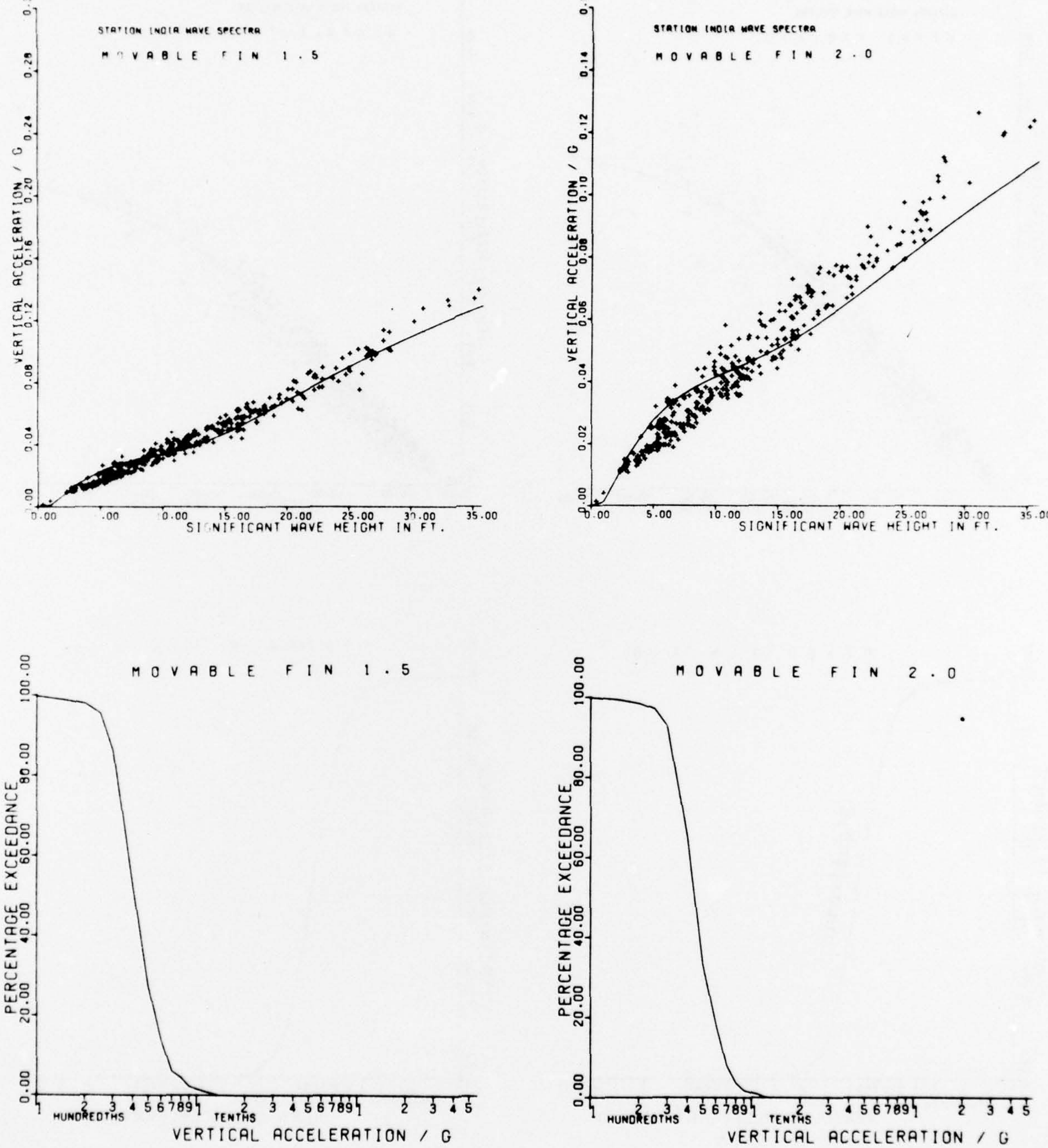

Figure 16 - continued

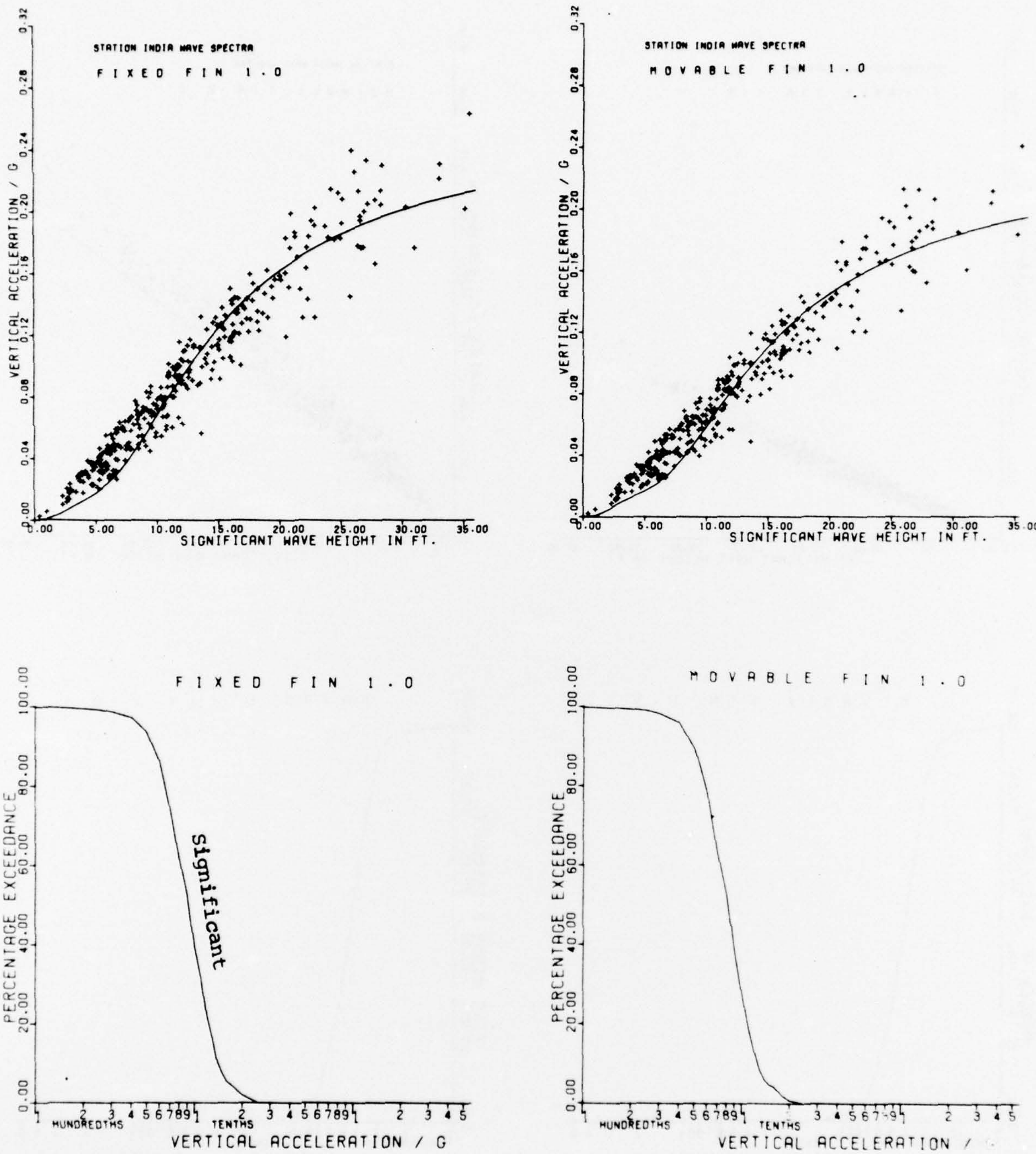

Figure 17 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Aft End of the Strut for 5 Knots with Various Fins

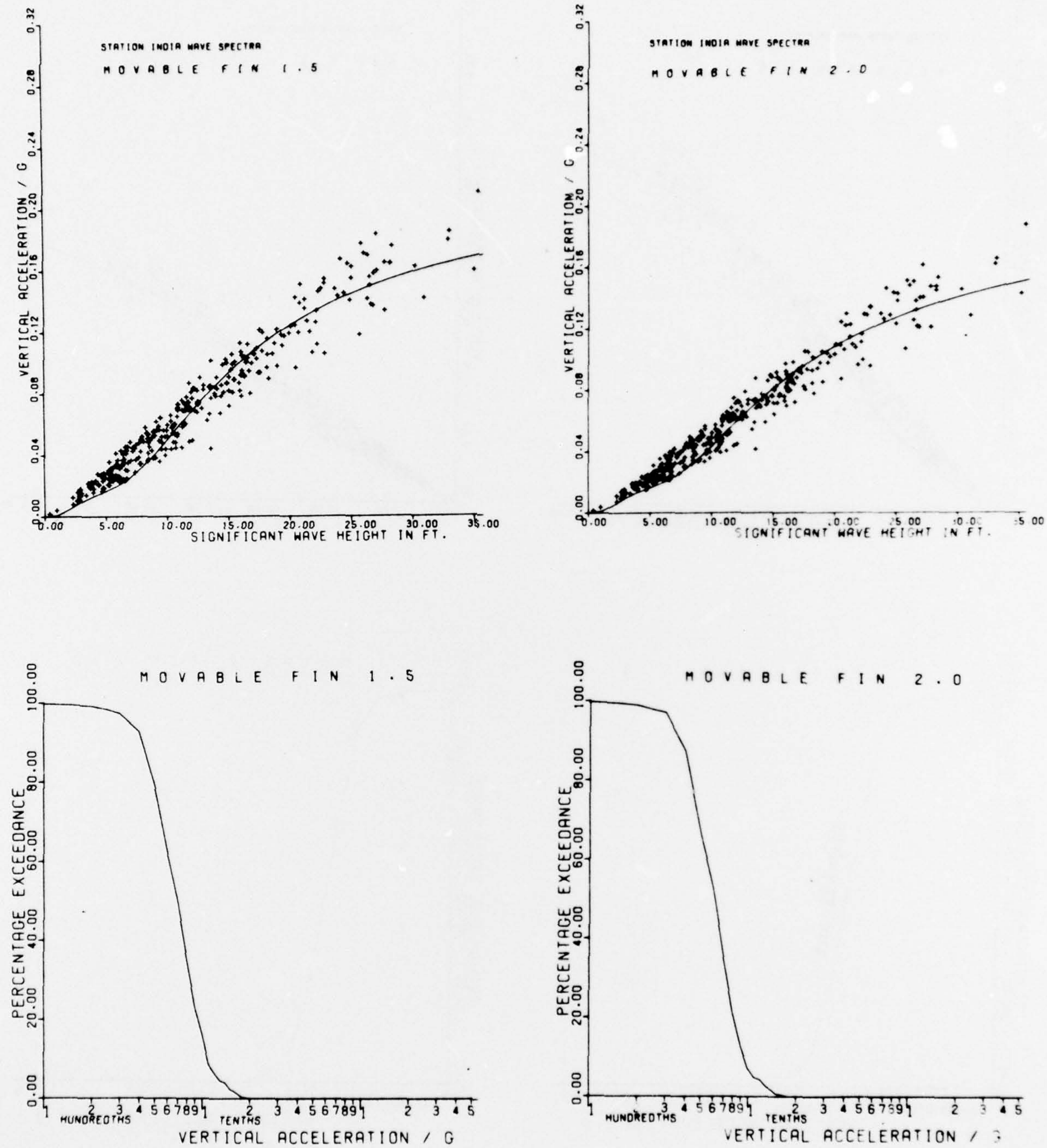

Figure 17 - continued

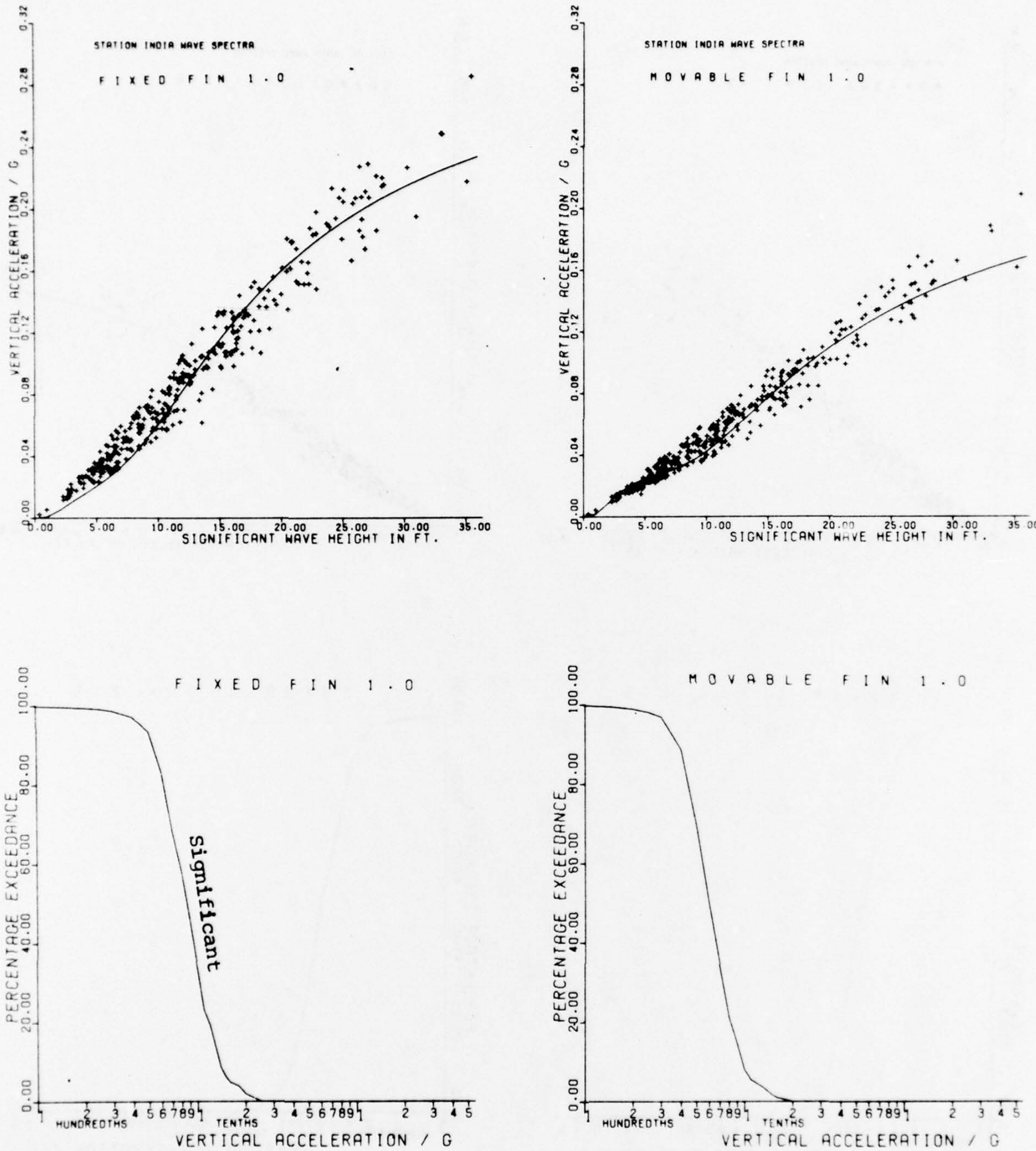

Figure 18 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Aft End of the Strut for 10 Knots with Various Fins

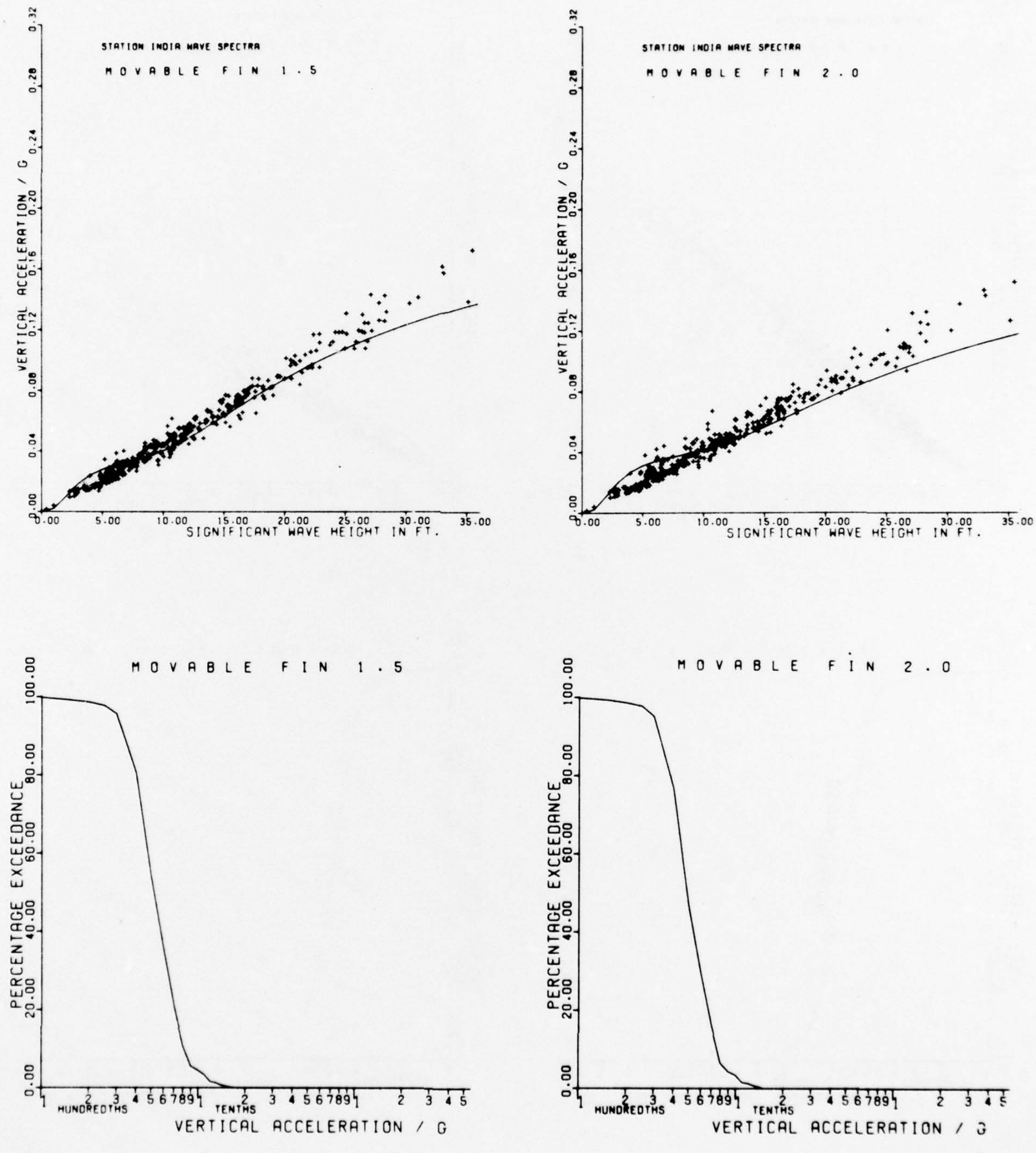

Figure 18 - continued

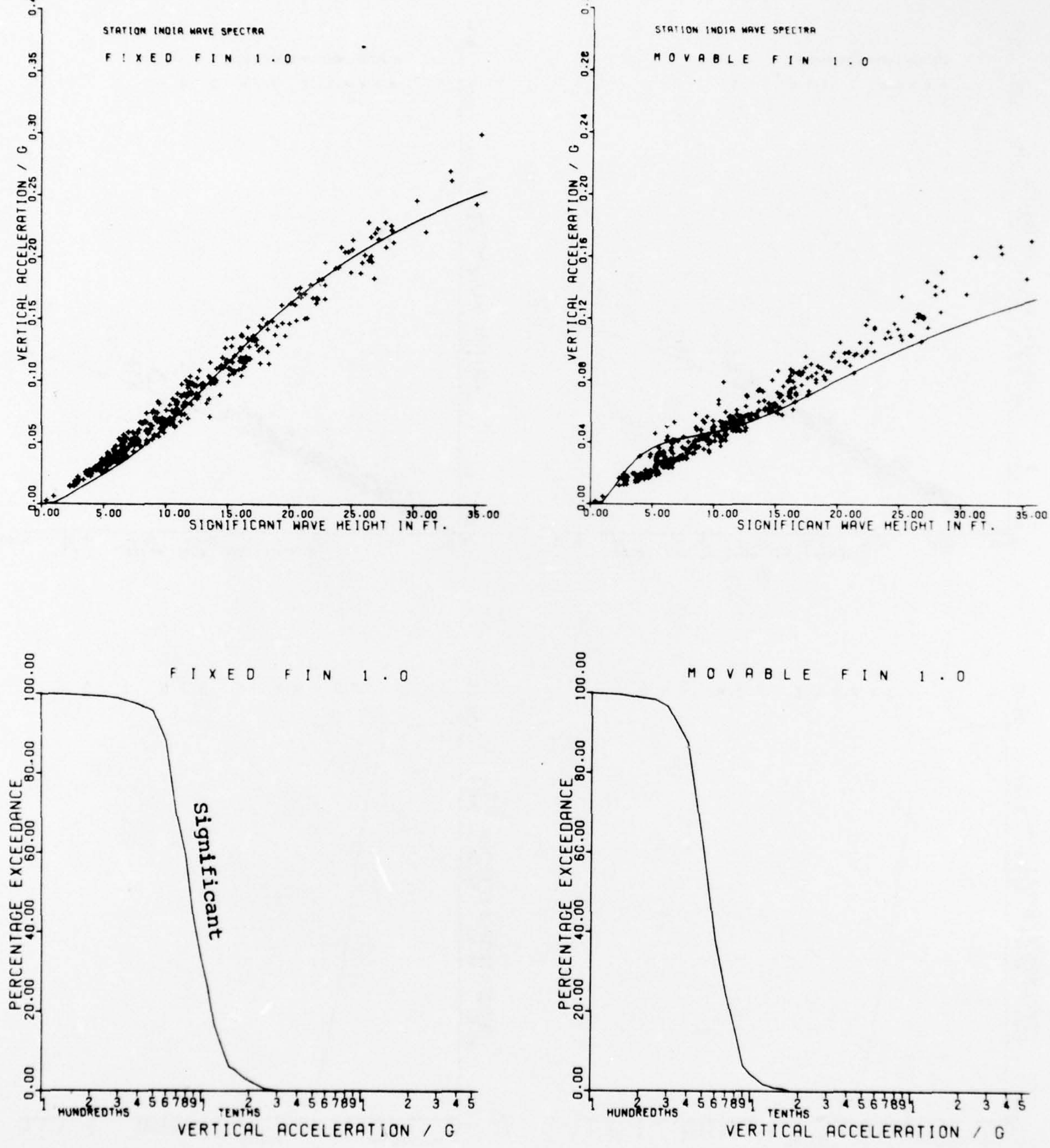

Figure 19 - Significant Amplitude of Vertical Acceleration and Percentage Exceedance at the Aft End of the Strut for 15 Knots with Various Fins

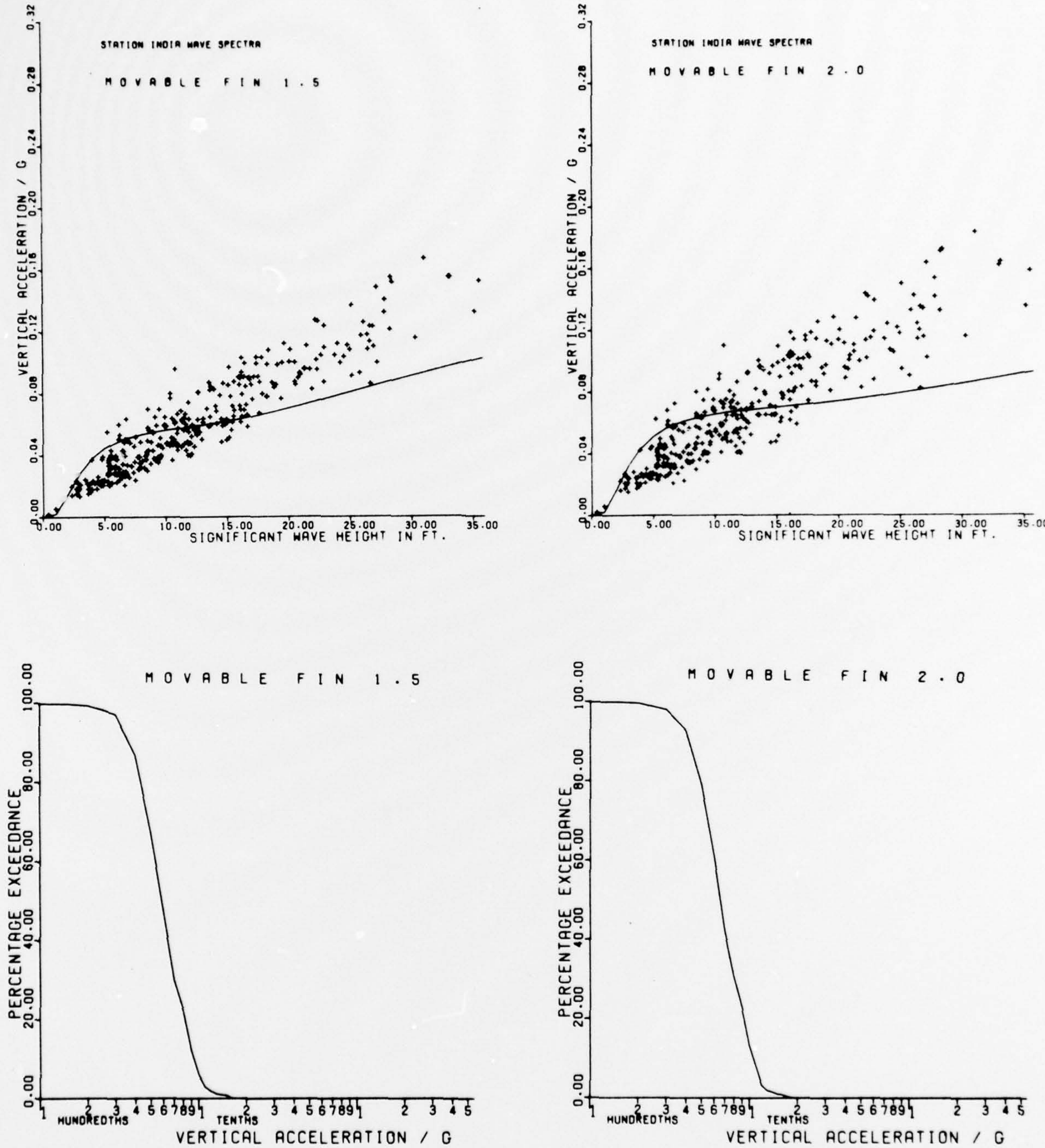

Figure 19 - continued

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